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AFSHAR, ZAHRA

Mobility and Economic Transition in the 5th to the 2nd Millennium B.C. in the Population of the Central Iranian Plateau, *Tepe Hissar*

Zahra Afshar

Ustinov College

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Abstract

Mobility and economic transition in the 5th to the 2nd millennium B.C. in the population of the Central Iranian Plateau, *Tepe Hissar*

Zahra Afshar

Iranian archaeology has had a keen interest in exploring unexplained events occurring during the 5th to the 2nd millennium B.C. on the Central Iranian Plateau. This is represented by transformations in material culture, a differentiation in mortuary practices, and site abandonment and reoccupation, and has traditionally been explained by the influx of new populations into Central Plateau sites. The site of *Tepe Hissar*, the subject of this research, located in the north east region of the Central Plateau and appears to have undergone these changes during its existence (late 5th to the early 2nd millennium B.C.). This research uses a bioarchaeological approach to tests the hypotheses that the socio-cultural-economic changes that occurred at *Tepe Hissar* over time, accompanied by influxes of new people into the site, particularly in Hissar periods II and III; ultimately impacted on subsistence economy, diet, and general health, and also resulted in a rise in tension and interpersonal violence.

The biological affinity data suggest that the changes at *Tepe Hissar* were not accompanied by large scale population replacement/immigration/or invasion. Rather, there was more small scale population replacement over time, although these changes were accompanied by interpersonal violence. These changes did not greatly impact on the general health of people over time, although people in each period experienced different frequencies of stress and disease, and periods of malnutrition; both females and males were affected equally in each period.

The dental disease data showed that changes during Hissar II and III had a significant impact on the oral health of people, and Hissar I experienced better oral-health compared to later periods; this may be due to changes in subsistence economy and diet, food preparation techniques, and how the teeth were used as tools. The data indicate that males possibly suffered poorer dental health compared to females at this site; they may have had a different diet, or possibly used their teeth as a third hand more than females.

The isotopic data (C/N) showed that the inhabitants had access to similar food resources across all periods; individuals from each period, both sexes from different age-categories, had a similar diet based on C3 plants and animal protein, as well as a small contribution from fresh water resources.

Overall, this research suggests that the society who lived at *Tepe Hissar* overall may have had an appropriate social structure and adequate food resources to withstand socio-cultural-economic changes, enabling the community to be more centralised socially, economically, and politically such that the changes and events they experienced did not markedly affect their health or nutritional status.

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Chapter 1 : INTRODUCTION

Archaeologists usually focus their research on a range of materials that represent past peoples and from these finds they attempt to draw inferences about how people lived and their general well-being. However, based on archaeological theories that might explain similarities and differences seen at archaeological sites, archaeologists have long been interested in tracing population movements and biological relationships between people who produced the archaeological record (Rouse, 1986:14; Anthony, 1990; Hegmon et al., 2000). They have commonly used cultural changes as an explanation for population change (Lindauer, 1995). For example, the presence of particular artefact typologies at a site, and subsequent changes through time, is often accepted as representing different groups of people (Lindauer, 1995; Hegmon et al., 2000). However, archaeologists need to consider whether changes in material culture are reflected in the biological characteristics of the people who created it (Lahr, 1996:4), or whether the changes just reflect acculturation of an *in situ* population (Rouse, 1986:14; Lindauer, 1995). It is here that bioarchaeological studies of human skeletal remains can provide a unique perspective which cannot be offered by archaeological materials alone, and can be a complementary source of information that can contribute to the interpretation of an archaeological site. Human skeletal remains offer valuable data for evaluating biological relationships/distance between human groups (Pietrusewsky, 2008:487; Walker, 2008:14), along with suggesting aspects of their lifestyle, mortality rates, diet and nutrition, and health and disease (Scott, 1997). This provides an extraordinarily detailed picture of the physiological responses of past populations to the stresses and tensions posed by their environments (Walker, 2008:15).

This study explores the value of human skeletal analysis for providing direct evidence for population affinity and the impact of socio-cultural and economic changes on the remains of people buried at *Tepe Hissar*, located in north-eastern part of the Central Iranian Plateau during the Chalcolithic and Bronze Ages (late 5^{th}-early 2^{nd} millennium B.C.).

1.1. Background to the Project

For a long time Iranian archaeology has been interested in exploring unexplained events that occurred during the 5^{th} to the 2^{nd} millennium B.C. in the Central Iranian Plateau, represented by transformations in material culture, including stylistic changes in pottery and metallurgy, a differentiation in mortuary practices, standardized craft

production, and evidence for long distance trade (Fazeli et al., 2004, 2007, 2009, 2010; Majidzadeh, 2008). Site abandonment and reoccupation occurs periodically across the plateau (Marshall, 2012:346), and has traditionally been explained by the arrival of new populations into Central Plateau sites (Schmidt, 1933; McCown, 1942; Majidzadeh, 2008:73).

Fig 1.1. Map of Iran and geographic location of Tepe Hissar and neighbouring sites (redrawn from google images)

Tepe Hissar, the focus of this research, is one of the largest known urban settlements in the northeast of the Central Iranian Plateau (Figure 1.1) and is a key site in terms of the archaeological landscape; it is located on the major trade routes along the "Silk Road" which connects Central-Asia in the East to Mesopotamia in the West and the Persian Gulf (Pigott et al., 1982). This site can potentially contribute to a better understanding of cultural interactions and developments, population replacements, and overall the events that appear to have occurred during the Chalcolithic and Bronze Ages (late 5th- early 2nd millennium B.C.) in the Plateau. It is also important for providing a clearer picture of interactions between people living on the Iranian-Plateau and the Indo-Iranian borderland sites during that time. The archaeological sequence at *Tepe Hissar* indicates a sudden appearance and proliferation of the settlement (Hissar I period) in the late 5th millennium B.C at this site (Schmidt, 1937; Majidzadeh, 1981, 2008:69,74). This raises the question of where the inhabitants of this site originated; archaeological material suggests population movement from other abandoned sites (e.g., Sialk) on the Central Plateau (Majidzadeh, 2008:73). During the mid-early 4th millennium B.C. (late Hissar I),

there is evidence showing that this site underwent an extreme cultural shift and entered a new era, or Hissar II period, suggesting migration from the Turkmenistan Steppes (Schmidt, 1937). The appearance of "grey pottery" followed by the disappearance of the "painted pottery" of Hissar I, coupled with a remarkable increase in industrial activities, suggests the arrival of "Hissar II people" into the site. Archaeological materials from the Central Plateau (e.g., Qazvin and Kashan plain) indicate that this cultural change is paralleled by a break in cultural unity and contact between people living at sites in the Central Plateau (Majidzadeh, 1981, 2008:77; Fazeli et al., 2009). The archaeological evidence suggests that, following this shift, the people of Hissar I may have left the site and moved into the western regions of Iran (McCown, 1942). Nevertheless, the evidence of "fire", "ashes", "burnt human remains", and "destruction" in buildings dated to Hissar II suggests that these cultural changes may have been accompanied by "traumatic" events, particularly at the end of Hissar II (IIB).

Nevertheless, in the very early 3rd millennium B.C. (early Bronze Age, late Hissar II), *Tepe Hissar* underwent a second cultural transition, suggesting that "dynamic force" or "foreign influence" changed life during Hissar II with another new era entered (Hissar III-Schmidt, 1937). Hissar III is the era of grey pottery. However, the evidence of "burning and destruction" in buildings from the beginning of the Hissar III period, "charred" human skeletal remains, as well as the occurrence of "mass burials", suggests that during this time, particularly from the middle to late period, the site may have experienced intra- or inter-group conflict/violence (Schmidt, 1933, 1937) and that these cultural changes were not peaceful. The occurrence of specific archaeological material in late Hissar III, such as Central Asian cultural evidence (BMAC: Bactrian-Margiana Archaeological Complex, Figure 1.1) (e.g., alabaster, calcite objects and miniature columns) and "warriors" suggests movements of people from Central-Asia (possibly the Indo-Iranian movement into the Indo-Iranian borderland and the Central Iranian Plateau) but also indicates more of an "intrusion" and "organized warfare" rather than "trade" (Hiebert and Lamberg-Karlovsky, 1992; Parpola, 1998:124; Hiebert, 1998:151-155;Lamberg-Karlovsky, 2002). The archaeological data from Hissar III shows interaction of the people there with north-eastern Iran (Gorgan plain) and the Namazga sequence sites of southern Turkmenistan (Mousavi, 2008; Thornton et al., 2013). However, the question remains as to whether the cultural transformations that occurred during different time periods at *Tepe Hissar* actually reflect the "arrival or departure of different people with different cultures", "invasion", or "biological continuity", whether

there is any evidence for subsistence changes and dietary diversity for the different periods, and what impacts occurred on the general health of the population. There has been no holistically grounded bioarchaeological study of *Tepe Hissar* populations to assess biological affinities or distances between individuals in each period or within periods, or to assess the impact of these cultural changes at this site on lifestyle, subsistence economy, diet, or general health.

To test the hypotheses proposed below, the principal aim of this study was to determine if the *Tepe Hissar* populations shared close biological relationships, or if they represented distinct biological groups within and between periods. Ultimately, this was to investigate whether changes reflected in the archaeological material at this site were caused by "biological replacement", or that cultural development occurred without biological changes. The research also investigates the impact of cultural changes on general health/stress, subsistence economy, diet, and interpersonal conflict within and between the periods analysed, by sex and age. In order to explore these ideas, the following hypotheses are tested and questions posed.

1.2. Hypotheses and Research Questions

Hypothesis 1

The inhabitants from Hissar I period are a homogenous population and possess close biological affinities, which are represented in the associated material culture; both have continuity within this period.

Questions

1. Are the data from metrical and non-metrical analysis consistent for all individuals from Hissar I?
2. Are the funerary and material culture data consistently the same throughout this period?

Hypothesis 2

a: There are similarities and dissimilarities in biological affinities between individuals/groups of people from the Hissar II and III periods, suggesting influxes of new people

b: There is no biological continuity between the three periods at Tepe Hissar, due to population replacement in each period.

Questions

1. Are the data from metrical and non-metrical analysis consistent or inconsistent across all individuals from Hissar I, II and III?
2. Are the funerary and material culture data consistently the same throughout all periods?

Hypothesis 3

The cultural and economic transitions and possible population changes that occurred at Tepe Hissar, and particularly in Hissar II and III, impacted on their subsistence economy, the diet people ate, and their general health, and also resulted in a rise in tension and interpersonal violence among this population; this also differed between males and females.

Questions

1. What type of diet did people from each period eat?
2. What health problems did they suffer?
3. Did they experience interpersonal violence?
4. Were there differences between males and females?
5. If there were differences, do they suggest anything about the status of males and females in society?

1.3. Significance of Research

Questions about the origin, language, biological affinity, mortality, demography, disease, health, conflict, and diet of the population of *Tepe Hissar* cannot be easily answered as there are no contemporary written records that can tell their story. Most of what is known about this population is based on inferences derived through analysis of archaeological materials.

Currently, comparative analysis of human skeletal remains is rare in Iran, and this study is the first to integrate the archaeological evidence for cultural changes with bioarchaeological analysis of the skeletal remains of individuals from Chalcolithic and Bronze Age populations of the Central Iranian Plateau. Furthermore, carbon and nitrogen stable isotope analysis of the skeletal remains has provided the first such data on diet in this population and provides a powerful tool in the quest to understand this population during the 5th to the 2nd millennium BC. The skeletal series from *Tepe Hissar,* with a total 397 individuals, is the largest human skeletal collection from the Chalcolithic and Bronze

Age periods of the Iranian Plateau, provides a particularly good data set for investigating these questions, because it contains remains from the early to the late occupation of the site.

1.4. Structure of the Thesis

This thesis is structured into nine chapters. Chapter 2 gives detailed information about the prehistoric Central Iranian Plateau and the Chalcolithic and Bronze Age periods of *Tepe Hissar* (late 5^{th} to the early 2^{nd} millennium B.C.). This chapter also gives a detailed description of the archaeological evidence and cultural sequences of this site as seen from the excavations, alongside, an overview of the make up of the graves of the inhabitants and previous research done on the skeletal remains. Chapter 3 reviews metrical and non-metrical trait analysis of skeletal and dental remains. Literature concerning the development of the use of skeletal and dental metrical data, as well as non-metric traits, to determine biological affinity within populations is outlined. In this chapter the contribution of craniofacial and dental metrical analysis in the study of ancient Iranian population history is also highlighted. Chapter 4 discusses skeletal and dental indicators of stress. In this chapter a detailed description of metabolic and dental diseases both based on clinical and paleopathological data is outlined. This chapter also presents a description of the study of trauma and interpersonal violence. Chapter 5 reviews the principles of the carbon and nitrogen isotopes used in this study enabling paleodietary reconstruction. Chapter 6 describes the skeletal materials and the analytical methods used. Chapter 7 documents the results of the analyses, including comparative statistical analysis of the data within and between periods. Chapter 8 discusses the data in the context of the research hypotheses and questions, and Chapter 9 presents a conclusion of the findings, limitations of the research, and suggestions for future research.

Chapter 2 : THE ARCHAEOLOGICAL CONTEXT OF THE CENTRAL IRANIAN PLATEAU AND TEPE HISSAR

This chapter provides relevant contextual information regarding the prehistoric Central Iranian Plateau- the Chalocolithic and Bronze Age (late 5th to the early 2nd millennium B.C.) site of *Tepe Hissar*, the archaeological sequence of this site, the graves of the inhabitants, as well as previous studies of the population. In addition, it explores the known socio-cultural and economic changes and events that occurred during the life of this ancient site to contextualise the potential impact these events may have had on the lifestyle of this population.

2.1. The Central Iranian Plateau

2.1.1. Environmental Context

The Central Iranian Plateau (Figure 2.1) is a huge area of irregular shape which lies in the central northern part of Iran with an average altitude of about 1500 m. with high mountains extending along the western and northern margins (Ganji, 1978:151). The northern part lies in the southern slopes of the Alburz Mountains, in the western part there is the largest salt basin (*Kavir-e Masileh)*, and on the north extending from west to east there are three smaller basins: *Kavir-e Sangfarsh* (rock-carpet), *Kavir-e Semnan*, and *Kavir-e Damghan*. However, the largest salt desert of the Iranian Plateau is *Kavir-e Bozorg*, or Great Kavir, and lies to the south and to the east of these smaller basins. It covers over 200 miles length with is more than 40 miles wide extending towards Khorasan to the northeast, Sistan and Baluchistan to the east, and Kerman to the southeast (Fisher, 1968; Majidzadeh, 2008:9). The climate of the Plateau is semi-arid and arid (Bobek, 1968:280). The temperature in summer is very high and almost over 50° C while in winter temperatures can drop below freezing point (Fazeli et al., 2002).

The Plateau is bounded by the Alburz Mountains in the north, which appear as an almost continuous wall encircling the coast of the Caspian Sea in the south, and continuing eastwards to the northern highlands of Kopet-Dagh (Fisher, 1968:38). Due to its high elevation (about 4000 m.), the Alburz Mountains receives a high rainfall which feeds several streams and rivers flowing both north to the Caspian Sea and south to the northern part of the Plateau (Roustaei, 2006). The interior areas of this region receive very little rainfall, about 3.18mm annually, but the exterior parts, especially those in the north and in the west, receive a considerably larger amount. The fertile part of the Plateau

consists of several geographical regions, including Damghan and Semnan in the northeast, Garmsar, Rayy, Tehran, and Karaj in the central part of the northern area, the Qazvin plain in the northwest, Saveh to the west, Qum in the central part and Kashan to the south (Majidzadeh, 2008:9). The *Silk Road* (or the *Great Khorasan Road*) passes through the Plateau, suggesting the earliest residents may have built and used this key road. Evidence shows that many ancient settlements in the Plateau were located along this road, connecting lowland Mesopotamia and South-Western Iran to North-Eastern Iran, Afghanistan and China (Voigt and Dyson, 1992a:164, 1992b; Majidzadeh, 2008:66-67).

2.1.2. Prehistoric Chronological Sequence (Table 2.1)

In 1942, McCown proposed three phases for the prehistoric Central Iranian Plateau: Sialk, Chashmeh Ali, and Hissar Phase (1942:12-13). However, Majidzadeh divided the Central Plateau culture into four distinct periods: Archaic Plateau, Early Plateau, Middle Plateau, and Late Plateau (1981, 2008:30). Later, Fazeli and colleagues (2004) argued that these chronological outlines were based upon individual excavations, site type names and phases. However, based on radiocarbon dating, Fazeli et al. (2009) and Pollard et al. (2012) have proposed a new chronology and cultural sequence for the Plateau.

Table 2.1. The comparative chronology of Tepe Hissar and other prehistoric sites in the Iranian-Plateau (after [1]Majidzadeh, 1981; [2]Fazeli et al., 2009, 2004; [3]Pollard et al., 2012; [4]Thornton, 2009; [5]Roustaei, 2010)

[1]Period	[2]Period BCE	[3]Period BCE	[2,3]Qazvin plain	[2]Tehran Plain	[2] Kashan Plain	[2]Damghan/ Shahrud
		Iron Age III 800-550				Hissar Iron Age[5]
		Iron Age II 1200-800				Hissar Iron Age[5]
		Iron Age I 1550-1200	Shizar♣ Sagzabad♣			Hissar Iron Age[5]
		Late Bronze Age 1700-1550	Shizar♣ Sagzabad♣			?
		Middle Bronze Age 2200-1700	Shizar♣	? Central Grey-Ware[4]	? Central Grey-Ware[4]	Hissar IIIC[4] "BMAC burials"
	Early Bronze II (Kura-Araxes) 2900-2000	Early Bronze II (Kura-Araxes) 2900-2200	Shizar, Doranabad	Arasto Tepe	? Qoli Darvish[4]	Hissar IIIA?-IIIB (Burned Building)[4]
	Early Bronze I (Proto-Literate) 3400-2900	Early Bronze I (Proto-Literate) 3400-2900	Shizar	Tepe Sofalin* Shogali*	Arisman C Sialk IV	Hissar IIB
Late Plateau	Late Chalcolithic 3700-3400	Late Chalcolithic 3700-3400	Ghabristan III-IV Esmail Abad* Shizar Tepe Sagzabad♣	Cheshmeh-Ali* Tepe Pardis* Sofalin* Shogali*	Arisman B Sialk III 6-7	Hissar IIA
Grey Ware Middle Plateau	Middle Chalcolithic 4000-3700	Middle Chalcolithic 4000-3700	Ghabristan II Shizar	Cheshmeh-Ali* Tepe Pardis Shogali*	Sialk III 4-5	Hissar IC
Plum Ware	Early Chalcolithic 4300-4000	Early Chalcolithic 4300-4000	Ghabristan I	Cheshmeh-Ali* Tepe Pardis Shogali*	Sialk III 1-3	Hissar IA-IB*
Archaic and Early Plateau — Transitional Chalcolithic — Late 4600-4300			?	Cheshmeh Ali* Ismailabad* Kara Tepe* Shogali*	?	Shir Azhian* Aq Tappeh*
Archaic and Early Plateau — Transitional Chalcolithic — Early 5200-4600			Ebrahim Abad Zagheh	Cheshmeh-Ali Tepe Pardis Ismail Abad	Sialk North*	"Cheshmeh Ali" Phase*
Late Neolithic — Late 5600-5200			Chahar Boneh Ebrahim Abad	Cheshmeh-Ali* Tepe Pardis	Sialk North 4-5*	Sang-i Chakhmaq
Late Neolithic — Early 6000- 5600			Chahar Boneh	?	Sialk North 1-3*	"Djeitun" Phase

*without C^{14} dates (Fazeli et al., 2009)
♣ based on Pollard et al. (2012)

Based on archaeological data, Majidzadeh (1981, 2008) believes that there were two "intrusive" phases in the chronological sequence of the Plateau. These two phases are the "Plum-Ware" phase (late Early Plateau), dated to the Early Chalcolithic, or 4300-4000 B.C. (Fazeli et al., 2004, 2010), and the "Grey-Ware" phase (late Middle Plateau), dated to the late Middle Chalcolithic, or about 3700 B.C. (ibid). Majidzadeh (1981, 2008) suggests that these phases provide a probable reason for the change in the characteristics of settlements in the entire Iranian Plateau, due to the "invasion" of new people bearing their own cultural identity, and indigenous people migrating to other parts of Iran.

However, Fazeli et al. (2005) argue for continuity of the settlements in the Plateau from the Transitional to Early Chalcolithic period, which is in contrast to the general abandonment of sites as suggested by Majidzadeh (2008) and the suggestion of invasion/migration of the "Plum-Ware people" (Fazeli pers. comm. 2013). Coningham and colleagues (2006) also have discussed in particular the continuity of settlement seen at Tepe Pardis and Cheshmeh Ali in the Tehran region (northern Central Plateau) during these periods. Other studies suggest environmental changes, or socio-economic crises following extensive exploitation of human and natural resources, as the major factors causing abandonment or collapse of many settlements in south-west and east Central Iran rather than invasion (Fazeli et al., 2005).

Archaeological data indicate that the settlement of *Tepe Hissar* on the northeast corner of the Plateau was established at the end of the 5th millennium B.C (Fazeli et al., 2009, see Table 2.1), shortly after the "Plum-Ware" invasion (Majidzadeh, 1998, 2008:69,74). Uncovered sherds from "Shir Ashiyan" (Shir Azhian) (a temporary camp site situated 15km west of Damghan and 18km from *Tepe Hissar*) show close similarities to the oldest archaeological material from *Tepe Hissar*, or Hissar IA (Schmidt, 1937:41) as well as to Early Plateau pottery (Majidzadeh, 2008:73), suggesting the movement of displaced people in the Early Plateau period to the east.

Nevertheless, following a period of flourishing plateau settlements, archaeological data indicate that in the late Middle Chalcolithic, about 3700 B.C. (Fazeli et al., 2004, 2009, Table 7), there was a major disruption to the Central Plateau culture (Majidzadeh, 2008:74). The archaeological evidence shows that in the early 4th millennium B.C. (Fazeli et al., 2004) the Central Iranian Plateau progressed to a new era with the intrusion of "Grey-Ware people", namely those who had disrupted the cultural unity of all the Central Plateau sites (Majidzadeh, 2008:74-75). The archaeological data indicating this intrusion have been reported from many sites on the Plateau (e.g. *Tepe Hissar* and *Tepe Sialk*). There is evidence that the people of some settlements, for example the central *Qum* and northern *Rayy* regions, completely abandoned their settlements and never returned (see Schmidt, 1933, 1937; McCown, 1942:56; Majidzadeh, 1978, 1981, 2008). Does this intrusion/cultural shift reflect the presence of foreign people who came from their homeland and introduced a new style of pottery (Grey-Ware)?

Majidzadeh (2008:75) suggests that the appearance of intrusive Grey-Ware pottery immediately after the destruction of the Middle Plateau settlements cannot be accidental. The people who made this pottery could have been the major cause of the temporary

abandonment of *Tepe Sialk* and *Tepe Hissar*, as witnessed by archaeological discontinuity and the complete disappearance of the Middle Plateau population in the *Rayy* and *Qum* regions, and there is no evidence of a return (ibid: 2008:75). McCown (1942) also suggested that the settlement of *Tepe Hissar* (Hissar IC) may have ended as a result of gradual "infiltration" of Grey-Ware people who settled in Hissar IIA. Schmidt (1937) speculated that the late Hissar I (IC) period may have ended due to extensive invasion from the north from Turkmenistan, along with the introduction of grey ware pottery. Archaeological evidence shows the isolation of *Tepe Hissar* from the rest of the Central Plateau culture during the first-half of the 4th millennium B.C., losing its contacts with the west and south. This suggests the development of new connections in the north and north-east direction (Majidzadeh, 2008:76), possibly with the Gorgan region in the southeast Caspian Sea and Kopet-Dagh in southern Turkmenistan (Helwing, 2006; Thornton et al., 2013- see below), preserving their political independence from the *Uruk*/*Proto-Elamite* by making themselves economically self-sufficient (Thornton et al., 2013:142). Nevertheless, in the late 4th millennium B.C. many settlements in the Central Plateau, for example Tepe Ghabristan in the Qazvin plain, were deserted forever (Majidzadeh, 2008:77; Fazeli et al., 2009), and the northern Rayy and northwestern Qazvin plains remained uninhabited for centuries. The Godin V community ended, but *Tepe Hissar* and Sialk IV entered the Bronze Age period with a new culture about the beginning of 3rd millennium B.C. (Schmidt, 1933, 1937; Majidzadeh, 1981, 2008:77). During this period *Tepe Hissar* showed contact with northeastern Iran, the Gorgan plain and the Namazga sequence sites of southern Turkmenistan (Mousavi, 2008; Thornton et al., 2013). Nevertheless, it is interesting to investigate if these cultural changes were due to population movements?

2.2. The Site of *Tepe Hissar*

Tepe Hissar was inhabited during the late 5th to the early 1st millennium B.C through the historic to the Islamic period (Schmidt, 1937; Pigott et al., 1982; Thornton, 2009; Roustaei, 2006, 2010). Schmidt (1933:341) states that the first residents of this site were probably agricultural people whose origin and language is unknown; with no written records little is known about them.

Fig 2.1. Map of the Central Iranian Plateau and Tepe Hissar (redrawn from google images)

Tepe Hissar is a complex of disconnected irregular series of mounds and flat areas with a total area of about 12 hectares (Dyson and Tosi, 1989; see Figures 2.2 and 2.3). It is situated in the northeastern part of the Iranian Plateau near the southern slopes of the Alburz Mountains and the southeastern end of the Caspian Sea on the Damghan Plain (Figures 2.1 and 2.2). It is located on the southwestern limit of the large deltaic fan of the Damghan River which drains the southern side of Alburz between Semnan and Shahrod. The Damghan River originates from the Cheshmeh Ali spring, about 35km North-West of *Tepe Hissar*. The terminal branches of this river divide into several streams, feeding an area of about 200 km^2; one of them passes near *Tepe Hissar* (Dyson and Tosi, 1989; Roustaei, 2006). South of the delta the surviving waters flow sporadically towards the centre of a shallow basin, closed to the south by low limestone hills. The Alburz Mountains are the source of the waters which drained year round from the surface of the plain by the Damghan River and a few other main streams (Dyson and Tosi, 1989). The northwest winds dominate all year round at the southern edge of Alburz Mountains and bring precipitation to the area, especially in spring and winter. There is an estimated average annual precipitation of 92mm in the Damghan Plain. The mean annual temperature in the area is between 14.4^0C (in June-July) and in lowest $-17C^0$ in December-January (Meder, 1989:7-8). In the south of the Damghan Plain the Salt Desert or *Kavir* is located, which is inhabited at its rim only with wild animals such as gazelle (Schmidt, 1933:326).

Tepe Hissar is surrounded by land rich in natural resources (Tosi, 1989:34). The high valleys to the north of *Tepe Hissar* are rich in flint, lead, wood, fruit, and animals such as deer, stag, boar, fish, and fowl. The arid regions of the Salt Desert to the south are rich in copper, gold, turquoise, and semi-arid fauna with herds of gazelles and onagers (Dyson and Tosi, 1989). Geomorphological and ecological studies at *Tepe Hissar* show that the location of this site was ideal for settlement and early agriculture during the Chalcolithic and Bronze Age periods (ibid; Meder, 1989). The archaeobotanical material uncovered at *Tepe Hissar* include cereals, chaff fragments, legumes, fruits, and other plants, confirming that the early people at *Tepe Hissar* had mastered domestication of plants (Meder, 1989; Costantini and Dyson, 1990). In terms of fauna, animal remains uncovered represent domestic (72.7%) and wild mammals (27.3%) (Bos sp., Capra hircus, Aegagrus, Equus sp., Onager Hemysm Gazella sp., Ovis sp., Felis sp., Canis sp., Lutra sp., and Camelus cfr. Bacterianus), bird (Chukar, Alectoris Chukar), and large numbers of fish bones and molluscs (Meder, 1989; Mashkour and Yaghmayi, 1998; Radu et al., 2008). However, a richer spectrum of animals (goat, sheep, tigers, pig, lion, etc.) have been seen among zoomorphological materials found at this site in the shape of figurines made of clay or alabaster and images painted on pottery (Meder, 1989).

Dyson and Tosi (1989) state that during its life the site of *Hissar* exhibits a remarkable continuity of settlement and wealth, since archaeological data exhibited no evidence of *deltaic* (river) changes or a dramatic decrease in population density, or even economic marginalization. Nevertheless, *Tepe Hissar* is a reference point in the cultural sequence of the Central Iranian Plateau and surrounding areas. The site is located on the major trade routes along the "Great Khorasan Road" which connects Central-Asia in the East to Mesopotamia in the West and the Persian Gulf, and may have functioned as a trading focus during its life (Pigott et al., 1982). During its life the population of the site, however, experienced stressful situations.

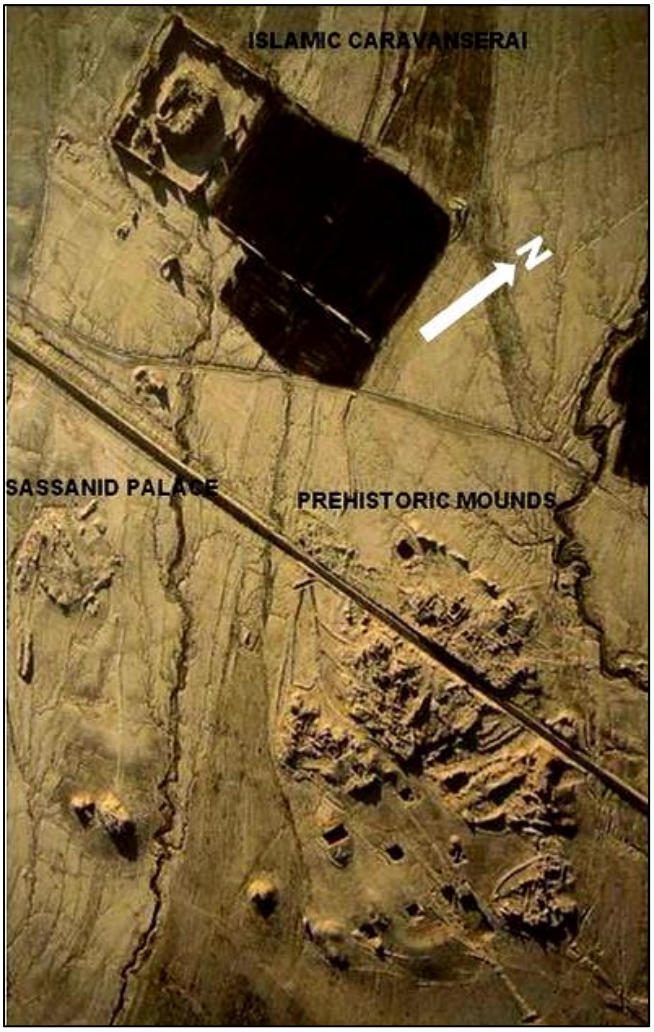


Fig 2.2. Aerial view of the site of Tepe Hissar (Mousavi and Sumner, 2012:Pl.19)

2.2.1. History of Research and Excavation at *Tepe Hissar*

In 1931-32 and 1932-33, before the Second World War, the prehistoric mound of *Tepe Hissar* was first systematically excavated by the University of Pennsylvania Museum under the direction of Erich Schmidt. Whereas initially Schmidt (1933, 1937) had started off building up stratgraphic sequence, he then moved over later to a typological sequence based on ceramics from the intramural burials found at the site (see Thornton et al., 2013). In 1971, Sumner, and in 1974 Sumner, Howard, Tosi and Bagherzadeh attempted to find more information about the stratigraphy, architecture, technology and ecology of *Tepe Hissar*. In 1972, Bulgarelli studied the flints from this site, and in 1976 Deshayes visited *Tepe Hissar* to restudy the surface sherds (Dyson, 1985; Dyson and Tosi, 1989). However, in 1976, a "restudy" project was undertaken by a joint international team from the University of Pennsylvania Museum, the University of Turin, and the Iran Centre for Archaeological Research (ICAR), under the direction of

Dyson and Tosi, to consider architectural and stratigraphic sequence and to answer many problems inherent in Schmidt's chronology (Dyson and Howard, 1989). Later, in 1995, a rescue excavation directed by Yaghmayi of the Iranian team (ICAR) uncovered many important archaeological finds, such as "cuneiform tablets" which are believed to belong to the Hissar IIIC period (~2000-1700 B.C.), and providing important data on interactions between the Plateau and Mesopotamia at that time (Yaghmayi pers. comm. 2012). In 2006, this site was surveyed and excavated by the ICAR, and resulted in the discovery of a cemetery and remains of Iron Age occupation (ca. 1500-500 B.C.), as well as strong evidence of an active river near *the site* (on the eastern and southern part of the site) contemporary with Hissar IB/IIA and Hissar II/III (Roustaei, 2006, 2010). The restudy project in 1976 showed that there were many changes at *Tepe Hissar* during its life, including its social organization, economic status, and technological development, and in its "foreign" interactions (Dyson and Remsen, 1989).

2.2.2. The Prehistoric Chronological Sequence of *Tepe Hissar*

The known prehistoric sequence at *Tepe Hissar* covers the late 5th to the early 1st millennium B.C (Table 2.1). It is divided into three major periods: the "Early Chalcolithic" period which is characterized by "painted" pottery (Hissar I), the "Bronze Age" period which is characterized by "burnished black and grey" pottery (Hissar II and III- Dyson, 1987; Dyson and Tosi, 1989), and the "Iron Age" period (red/orange/brown pottery- Roustaei, 2010). Apart from its long prehistoric sequence, the western part of the site was occupied in the Sassanid (late 600 A.D.- Talgam, 2004:50) and Islamic era (middle period- Schmidt, 1937:326-346; Roustaei, 2010). During extensive excavations at *Tepe Hissar* in 1931 and 1932, Schmidt divided the area of *Tepe Hissar* into seven major areas: North-Flat, Main-Mound, Red-Hill, Treasure-Hill, Painted Pottery-Flat, South-Hill, and the Twins (Figure 2.3). He produced an initial attempt at periodisation of the site, but subsequent work on his return to Philadelphia revised this scheme (1933, 1937), primarily based on seriation of pottery types found in the 1637 graves excavated (Dyson and Tosi, 1989). Schmidt (1937) identified three periods that were subdivided into 8 sub-periods: IA, IB, IC, IIA, IIB, IIIA, IIIB, and IIIC. However, he distinguished two of these phases as transitional: IIA is the transition between Hissar I and II, and IIIA is the transition between Hissar II and III.

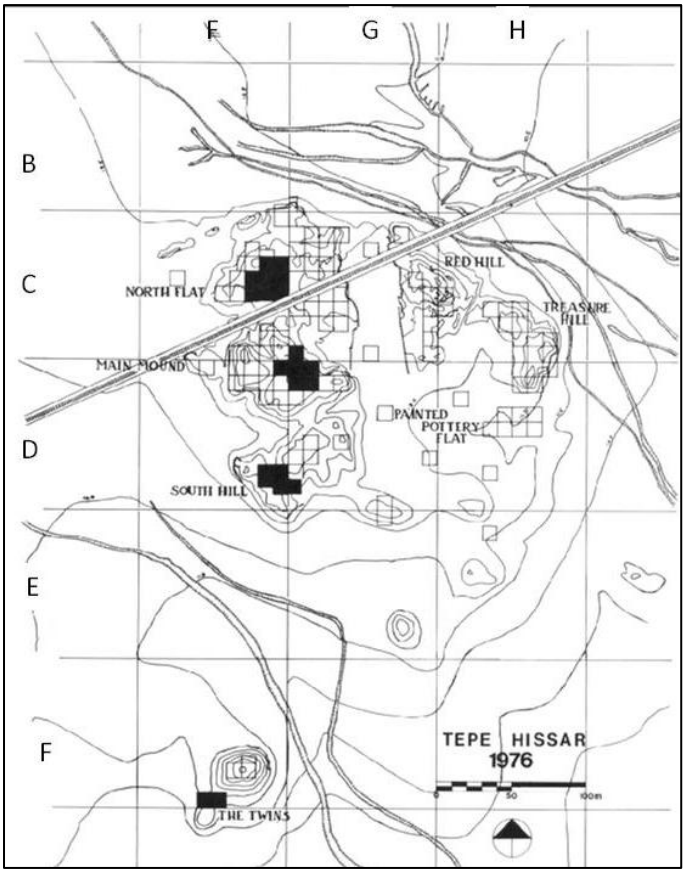


Fig 2.3. Plan of Tepe Hissar excavations: black squares (restudy team in 1976), and white squares (Schmidt, 1933, Dyson and Tosi, 1989)

During the restudy project in 1976 the stratigraphy, typology, and chronology of four areas (ca. 4300-1800 B.C.) on the Main-Mound (Howard, 1989), South-Hill (Tosi and Bulgarelli, 1989), North-Flat (Dyson and Remsen, 1989), and the Twins were examined independently, resulting in the first radiocarbon stratigraphic sequence for *Tepe Hissar* (Dyson and Howard, 1989- Table 2.2). Therefore, based on re-examination of the stratigraphy of the occupational sequence, pottery and radiocarbon dates the project identified a consistent stratigraphic sequence independent of Schmidt's burial sequence (Dyson, 1987). Different terminology has been used for the *Tepe Hissar* sequence by different scholars. For example, Dyson assigned phases A-D for the North-Flat, Tosi gave phases 1-8 for the South-Hill, and Howard and Pigott chose stages A-F for the Main-Mound. On the other hand, a separate scheme was chosen by Dyson (1987) for Hissar II period (Early, Middle, and Late Hissar II, see Thornton, 2009). Therefore, in order to determine the most likely sequence for the *Tepe Hissar* site, Thornton (2009) in his PhD research (unpublished) on the metallurgical remains reassessed, revised, and integrated previous schemes to provide a new sequence for this site (see Table 2.2).

Table 2.2. The different chronological sequence for *Tepe Hissar* (Schmidt, 1937; Dyson, 1987; Dyson and Howard, 1989; Dyson and Remsen, 1989; Howard, 1989; Tosi and Bulgarelli, 1989) (modified- from Thornton, 2009)

Thornton (2009)	Dyson (1987)	Schmidt (1937)	C^{14} BCE (restudy team 1989)	North-Flat Schmidt (1933, 1937)	North-Flat (Dyson and Remsen, 1989)	Main-Mound (Howard, 1989)	South-Hill (Tosi and Bulgarelli, 1989)
A		IIIC	2200-1800		**Phase A**"Hoard"	**Stage A** "wall" CG90, rich graves "Warrior"	
B		IIIB	2500-2200	"Burned Building" (CF46/47 + 56/57)	**Phase B**	**Stage B**	**Phase 1** "burial ground" (DF79/78)
							abandoned area
						Stage C1 "rectangular ovens with centring column" DG20	**Phase 2** building- pottery kilns
C		IIIA	2900-2500	diagonal wall	**Phase C**		
						Stage C2	**Phase 3** "burial ground" (DF78/79/88/89 + DG60/70)
						Burial ground??	abandoned area
D-C Trans	Late Hissar II	late IIB	3100-2900	CF57-58	**Phase C** "burned building" (chard skeletal remains of a child)	building 3	**Phase 4** "Lapis Lazuli" dump, pit, fish bones, wheat, barley, legume, flax (DF89) **Phase 5** "burned building" 4 **Phase 6** building (DF89) with remarkable change in plan-decrease in metal working-"freshwater fish (*Ciprinidae*)"
						Stage D1building 3 "fire"	
D	Mid Hissar II	IIB	3350-3100		**Phase C** lapis lazuli working	**Stage D2** "burned buildings" 1-2-3 (walls) "fire and destruction"	
						Stage D3 "burned building 1" (wall) "2 major fire, collapsed roof- burial ground", "burned building 2" "major fire/ rebuilding, building deserted", "burned building 3" major fire, charred reed, change in architecture and masonry	
							Phase 7 building-buttressed stairway structure-plastered storeroom (DF88/89), administrative/full metal working function
E-D Trans		early IIB	3400		**Phase D**	**Stage E1** "burned building 1" (Floor) (DF09)	
						Burial ground?	
							Phase 8 building (clay counter, figurines, and tablet, copper smelting slag), administrative function /full metal working
E	Early Hissar II	IIA	3650-3400		**Phase D**	**Stage E2-E3**	
F-E		IC/IIA	3700			**Stage F1-F2**(wall-melted brick and trash)	
F		IC	3900-3700			**Stage F3** (wall and ash)	

The following sections now outline the archaeological evidence from the three *Tepe Hissar* periods.

(i) Hissar I Period (ca. 4300-3700 B.C)- Painted Pottery and the Influence of Plateau Culture?

The Hissar I period, identified by Schmidt in the earliest layer of *Tepe Hissar* (1937:22, Figure.21), started in the Early Chalcolithic period and continued to the late Middle Chalcolithic period (Fazeli et al., 2009) (Table 2.1). It is assumed that this period may apply to the whole area (12 hectare) of the early occupation of *Tepe Hissar*, comparable with the other Chalcolithic sites in northern Iran and southern Turkmenistan (Dyson and Tosi, 1989). Schmidt states that the thickness and number of the occupation levels for Hissar I, and the presence of painted ceramics indicate continuous occupation during this early period (1937:20).

(a) Settlement and Building Remains

Schmidt showed that the architecture of Hissar I illustrates that the first citizens were already sedentary. Their houses were made up of small and medium sized rooms (Figure 2.4) and poorly built with sun-dried-bricks (*chineh*) without any trace of wall foundations or oven baked bricks (1933:342, Figure.A; 1937:27, Figure.24).

(b) Pottery

On the basis of ceramic variation, partly due to changes in technique but mainly seen in changes to design and the ground (baseline) colour, according to Schmidt (1937:39), period I falls into three different phases (A-C). The main pottery of this period was thin walled "painted pottery" (Figure 2.4), with a reddish or buff background with dark grey or brown decoration. The pottery shows advanced art, elaborate decoration and standardized forms; it was handmade in the earlier phase (IA) but turned to wheel made later on (ibid, 1933:344; 1937:39). The common form of painted pottery in Hissar I was that of chalice-shaped vessels, in the shape of stemmed jars, bowls, goblets, and conoid storage vessels (ibid, 1937:Pl.III-XI). Painted ware was present at *Tepe Hissar* until the late phase of occupation, comprising about 7.9% of the assemblage in use during Hissar III. However, the quantity of this ware decreased in relation to the predominance of grey ware in later periods (Dyson, 1985:340), the latter being entirely absent in the early phases (IA-IB-Early Chalcolithic), but few grey ware have been reported from Hissar IC (Schmidt, 1933:344, 1937:39; Dyson, 1985).

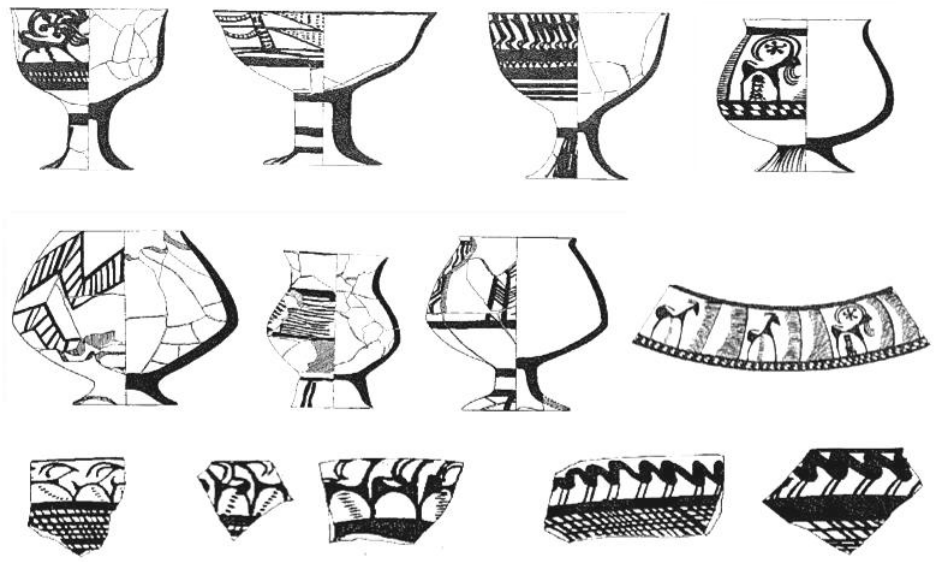


Fig 2.4. Examples of pottery from Hissar I (Schmidt, 1933:pl.LXXXVII)

The characteristic pottery from Hissar IA is handmade (Schmidt, 1933:pl.LXXXVII H1522, 1937:40) and decorated with geometric motifs (lines, zigzags, cross-hatched-bands, branches,and waves), the decoration being dark grey paint on reddish/brown or buff ware (1937:40-41, Figures 32 and 33,Pl.III). Studies indicate the similarity of Hissar IA pottery to that from "Shir Zhiyan" (Shir-Ashiyan-see above), as well as to the ceramics from Anau IA (black on a red background) in Turkmenistan (Hiebert et al., 2003:xvi, ca.4500 B.C.), Cheshmeh Ali in Rayy, and Sialk III_{1-2} in the northern Plateau (Schmidt, 1937:41,319; McCown, 1942:7). It is suggested that the early inhabitants of *Tepe Hissar* may have had interaction and/or communication with settlements in the Central Plateau and possibly from southern Turkmenistan (Fazeli pers. comm. 2013).

In Hissar IB, potteries turned to wheel made vessels, with few being handmade. Schmidt noticed that some graves (e.g., DH46 X-13) had both vessels typical of Hissar IA and characteristic vessels of Hissar IB, suggesting Hissar IB "followed" Hissar IA without any interruption; however, similarity in forms could show continuation in cultural development during Hissar I (1937:44,299). Schmidt (1937:299,321) indicates similarity between the Hissar IB culture and other sites in the Central Plateau (e.g., Morteza Gerd and Cheshmeh Ali in Rayy, and Sialk III_3), predicting that these sites may have influenced the development of the Hissar IB culture (see McCown, 1942:7, Figure.3). The main pottery for Hissar IB was buff ware (light brown) decorated with dark brown geometric and naturalistic animal and plant designs, in comparison with handmade and simple geometric motifs in the preceding phase. The most distinctive

patterns for this phase were conventional gazelles, rows of birds, floral scrolls and humans (Schmidt, 1937:Pl.IV-VI, see Figure 2.4).

The Hissar IC period began in the early fourth millennium B.C. This phase was reported by Schmidt (1933, 1937) and also the restudy project in 1976 by Pigott (Thornton, 2009). Both Schmidt and Pigott showed few grey ware sherds among the unpainted coarse and painted fine wares from Hissar IC (ibid; Schmidt, 1933:344, 1937:39). The form of vessels was similar to that of Hissar IA and IB with new elegant forms. However, the technology used for painted pottery reached its peak in compared with previous phases (Roustaei, 2006). The animal and geometrical motifs were similar to Hissar IA and IB, although new motifs were introduced, and the ground colour was lighter/grey white in IC (Schmidt, 1937:299,44). The characteristic decorative motifs for Hissar IC wares were conventionalized feline forms (e.g., leopard) (ibid:pl.VIII H4478, Figure.40 H4479), and ibexes with long curved horns enclosing the sun-symbol (ibid:pl.X H802, Figure.37 H4600); these appeared for the first time in Hissar I but were important guide pattern for Hissar IC. Again Hissar IC is identical in nature to SialkIII particularly to $SialIII_6$ (see McCown, 1942:10, Figure.4), as well as to Narges-TepeIV in the Gorgan-region (Abbasi, 2011:22). Schmidt (1937:299) noticed that some motifs such as dancing humans, plant and birds of the previous phase disappeared in Hissar IC. The study of the ceramics from the Main-Mound showed that the material and manufacturing techniques of all major painted wares such as red and buff ware were identical to each other (Dyson, 1985), suggesting the same clay sources were used (buff, red and even grey) and they were manufactured at the site (Dyson, 1987).

(c) Other Material culture

The archaeological evidence from the earliest settlement of *Tepe Hissar* showed an elaborate cultural assemblage indicating considerable wealth and craft specialization (Pigott et al., 1982). In addition to sophisticated pottery, objects such as spindle whorls, biconoid and conoid objects, figurines of baked clay, seals and seals-shaped ornaments, copper, stone objects (e.g., flint arrows, scrapers and flakes, whetstones), bone objects (awls, points), horns, and beads (e.g., gypsum, red-jasper, shell, carnelian, alabaster, serpentine, and bitumen) have been found dating to Hissar I (Schmidt, 1933:Pl.XC-XCIII, 1937:53-59 Pl.XIV-XVIII). Schmidt (1937:300) indicates that the appearance of spindle whorls could be associated with spinning of wool and the production of woollen clothing in this period. Copper objects uncovered at Hissar I show that the early settlers

of this site were familiar with copper implements and copper making technology in the late 5th millennium B.C. In early Hissar I, copper objects were simple/ornamented pins and needles, but in Hissar IC more sophisticated items such as daggers and knife blades appeared (ibid:301 PL.XVI- Figure 2.5). The occurrence of copper daggers, spearheads, and blades in some graves of IC as grave-goods (ibid:82) may indicate a possible increase in tension or competition among people at that time.

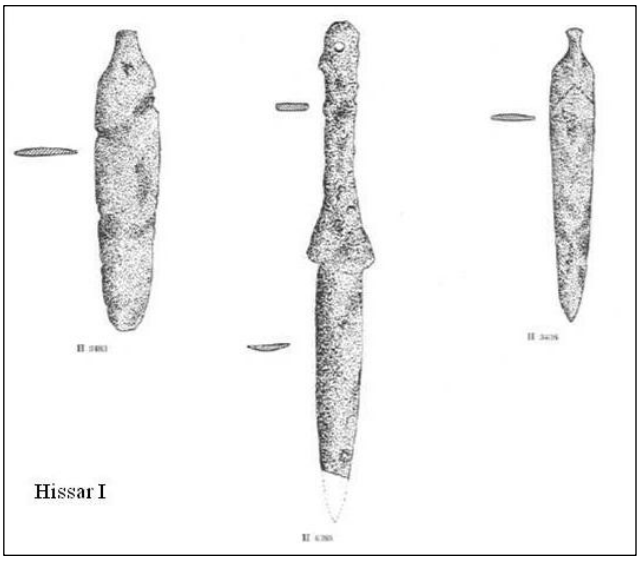


Fig 2.5. Copper dagger and blade from Hissar I (Schmidt, 1937:PL.XVI)

Some of the painted animal figurines, dated to Hissar I, have decoration mostly represented by shapes of sheep, dogs, goats, and cattle (Schmidt, 1933:Pl.XCII, 1937:54, Pl.XIV). These animal figurines suggest represent the animals that have been exploited for work or for food.

(d) Conclusion

Overall, the data show that the site during Hissar I experienced continuous cultural development and it is suggested that this period was more influenced by indigenous Central Plateau culture (Fazeli pers. comm. 2013). Archaeological evidence shows close similarity to Sialk III (McCown, 1942:7- Figures 2 to 4), Cheshmeh Ali, and Morteza Gerd in the northern part of the plateau (Schmidt, 1937:323). Nevertheless, the final phase of this period (Hissar IC, ca. 3700 B.C.) overlaps with, Hissar II (IIA) with the appearance of "grey ware" (ibid, 1937:108). McCown (1942:11) suggests that the gradual infiltration of "grey ware" people in early Hissar II ended Hissar I period. On the other hand, the appearance of many pottery types similar to the form and design of Hissar I culture found in latest layer of GiyanV (V_D) near Nihavand, McCown (1942:18, Figure.8) supports the movement of Hissar I people into the region of Giyan

during the Late Chalcolithic period (ca. 3700-3400 B.C.) possibly after the introduction of "grey ware" into *Tepe Hissar* around early Hissar II. The archaeological data suggest that the economy of the Hissar I period was based on agriculture, herding, metal and stone working, pottery, and possibly wool production (Schmidt, 1937).

(ii) Hissar II Period (ca. 3700-2900 B.C.)- The Introduction of Grey-Ware and the Question of Invasion

The Hissar II period (Schmidt, 1937:106) begins in the Late Chalcolithic and continues until the late Early Bronze I (Fazeli et al., 2009; Thornton, 2009) (Table 2.1). The appearance of grey ware was the main reason for defining this period by Schmidt (1933, 1937). Based on the changes in pottery, Schmidt divided the period into two phases, the earlier IIA (Early II- Dyson, 1987) and the later IIB (Mid II and Late II- Dyson, 1987). He (1937:302) interpreted this period as the arrival of new people ("Hissar II people") in the first-half of the fourth millennium B.C. He reported that occupation levels for the Hissar II period were thinner than Hissar I and Hissar III, suggesting either the period was short or occupation was not continued (ibid:26,106). However, radiocarbon dating does not support this suggestion and shows a large span of time of about 700 years for this period.

(a) Settlement and Building Remains –Buttressed walls, Burned Buildings

Schmidt (1937:106) recognized no difference between the buildings of Hissar I and II. He stated that in both periods houses comprised rows of rectangular rooms built in a haphazard manner with rectangular mud-bricks; "Chineh" (sun-dried-bricks) walls were used less frequently in this period. However, the later restudy project showed that the houses in Hissar II were not haphazardly built, but rather the masonry was well executed and the houses had a sophisticated and carefully planned architecture, with a large central enclosed room with additional smaller storage rooms, much different to those dated to Hissar I (Tosi and Bulgarelli, 1989; Dyson and Remsen, 1989:89). They uncovered "buttressed" walls (characteristic structure of Hissar II building), staircases, plaster on the walls, central hearths, and niches in the buildings of Hissar IIB (Howard, 1989:56- Figure.1; Dyson and Remsen, 1989:83- Figure.7). The occurrence of quernstones in each house indicated that people had prepared their own grain for cooking. The 1976 restudy project recognized four buildings dated to Hissar IIB (ca.3400-2900 B.C.), three (1,2,3) on the Main-Mound and the fourth building was

found on the South-Hill . Each building had several major rooms (Howard, 1989; Tosi and Bulgarelli, 1989; Voigt and Dyson, 1992a:170, 1992b). They noted that a "major fire" and destruction had occurred in the four buildings at the beginning of Hissar IIB (Howard, 1989:60). The archaeological evidence also shows that after the fire the buildings' rooms were renovated, plastered, and reused, but some rooms were blocked up (Howard, 1989:60; Dyson and Remsen, 1989:82).

Regarding radiocarbon dating it is suggested that buildings 3 and 4 may have been burned in the same incident, but there was no evidence to suggest the entire settlement of Hissar II was burnt at the same time (Dyson and Remsen, 1989:82). Moreover, Dyson and Remsen (1989:99,102) also uncovered a building in the North-Flat which was destroyed by fire (ca.3150-2905 B.C.), and suggested that it may relate to late Hissar IIB or the very early part of Hissar IIIA. In the building they found burned and scattered skeletal remains of a child in a room mixed with the fill of the south east corner of that room in addition to some pottery. The painted pottery in this building was also similar to that of IIIA and IIIB, but some of it was of classic period IIB, which suggests it being earlier than the "Burned Building" of Hissar IIIB (ibid:100-102-Figures.26-34). Nevertheless, the data suggest that Hissar II people may have left the area after the last fire in the Main-Mound, around the early 3rd millennium B.C. (Early Bronze Age) since the evidence shows that the area was turned into a burial ground (Howard, 1989:57-see Table 2.2). This phenomenon can be seen in the South-Hill and North-Flat and there is a gap in the chronological sequence for these areas at that time. It is suggested that the cultural transitions in Hissar II, particularly in Hissar IIB (~3400-2900 B.C.), may have not been peaceful as there was evidence of frequent destruction and fire of the buildings during this time. The changes in the buildings were contemporaneous with other significant cultural shifts (see below) in this period and were different from Hissar I period.

(b) Pottery

The separation of the Hissar I and II periods was mainly based on the appearance of unpainted dark grey ware (see Figure 2.6) in the graves containing painted ware of Hissar I (Hissar IIA ca. 3700-3400 B.C. Late Chalcolithic period; see Figure 2.16-Schmidt, 1937:108). As mentioned above, these ceramic changes have been reported from other Central Plateau sites (see above). The technique used, form, and colour of Hissar II painted pottery were very similar to those from Hissar IC (ibid, 1933:Pl.CII,

1937:Pl.XX-XXII, XXIV). The grey ware of Hissar II was wheelmade, polished or mat, in the form of bowls, jars, and goblets, identical to some of the earlier painted pottery forms. However, new forms were introduced for the first time at this site, e.g., tall stemmed bowls or goblets, unstemmed bowls and jars, and neckless jars (ibid:Pl.CI, 1937:Pl.XXIII, XXV-XXVI). The painted pottery of early Hissar II (IIA) had geometrical motifs similar to the earlier phase, including dark brown vertical and angular lines on a light greyish brown base (Schmidt, 1937:110-Figure.66 H4518), as well as zigzags and hatched bands encircling vessels in dark grey on brown/red or in brown on buff (ibid:109, Pl.XXII H4683, H4676). However, Schmidt points out characteristic "new" patterns, such as highly conventionalized long-necked-gazelle painted dark brown on a smooth light greyish brown base, and suggests this as being the key indicator for Hissar IIA (ibid:Pl.XX H4665,H4470). The decoration of feline forms (e.g., leopard) in early Hissar II continued in an almost similar manner to Hissar IC (ibid:Pl.XXI H4749 H4460), although leopards changed to being headless and tailless later in this period, and of dark brown/grey on a light grey/brown base (ibid:Pl.XXI H4460). However, birds and ibexes disappeared. Nevertheless, Schmidt believed that changes from painted pottery to grey plain pottery was not without external influence, and was perhaps due to large scale infiltration or actual invasion of people from Turkmenistan Steppe in the north of the Alburz Mountains (Schmidt, 1937:302). On the other hand, McCown (1942:50) proposed that a second infiltration of people during Hissar II (Hissar IIA) may have ended by the invasion of people in Hissar IIB.

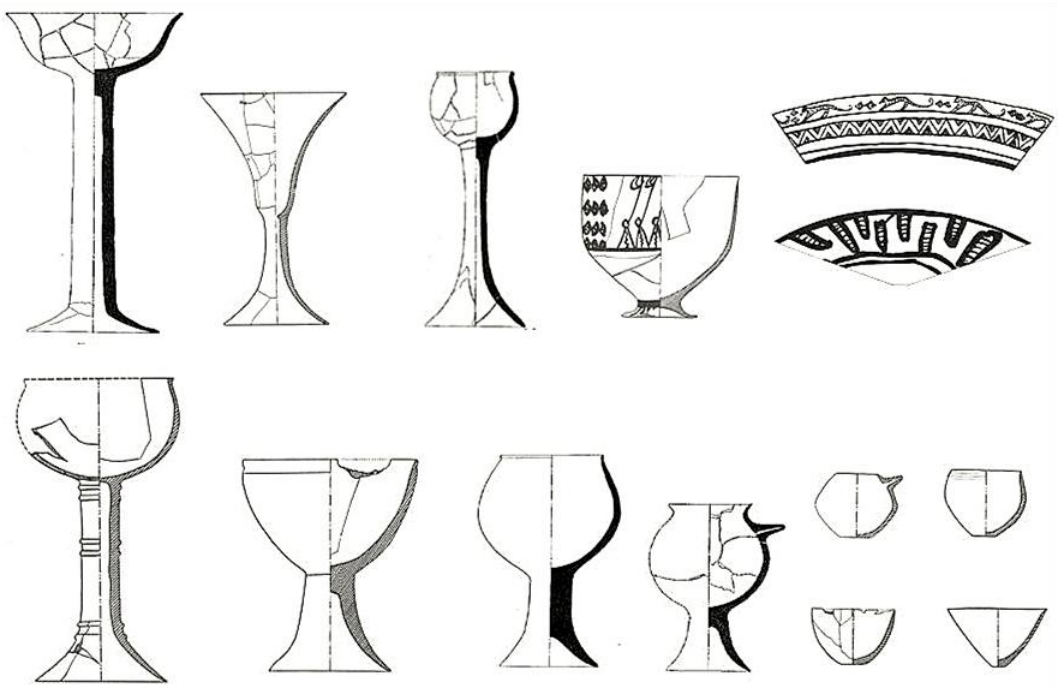


Fig 2.6. Examples of pottery from Hissar II (Schmidt, 1937:pl.XX to XXVI)

Hissar IIB (ca. 3400-2900 B.C.) is contemporary with the Early Bronze Age of Iran. In Hissar IIB new artifacts appeared but few elements from Hissar I survived. At this time grey ware predominate and painted ware (prevalent in Hissar I) decreased and was replaced with plain pink or buff coarse ware (Howard, 1989:66-Table.2; Schmidt, 1937:Pl.XXIV). The painted pottery of Hissar IIB contained simple linear and geometrical motifs with brown lines decoration on yellowish smooth surfaces, some being decorated with purple/brown motifs on a buff base (Schmidt, 1937:Pl.XXIV H3906, H4780). A new pattern of rows of crossed hatches circle (ibid:H1872) were a characteristic pattern for painted pottery for this period. Schmidt indicates that there was a similarity in form and colour between the grey ware of Hissar IIB and IIA (ibid:116), but the characteristic grey ware of Hissar IIB consisted of wheel made chalices with polished greyish surfaces (ibid:Pl.XXV H2784). Nevertheless, Hissar II ceramics showed close similarity to those from northeastern Iranian sites, such as Turang Tepe IIB (Voigt and Dyson, 1992a:171) and Bronze Age Narges Tepe, Shah Tepe, Turang Tepe in the Gorgan region (Abbasi, 2011:22; Thornton, 2013). It is suggested that during the 4th millennium B.C. *Tepe Hissar* was more influenced by the Gorgan region rather than the Central Iranian Plateau as a whole (Helwing, 2006; Thornton et al., 2013; Fazeli pers. comm. 2013).

(c) Other Material Culture- Metal working, Lapis Lazuli

Objects such as miniature vessels, spindle whorls, disks, and animal figurines were similar to Hissar I objects. However, human figurines were "new" for Hissar IIA (Schmidt, 1937:Pl.XXVII H3644, H3735, H2978). Seals were less common in Hissar II than in Hissar I, and a total of 191 seals discovered by Schmidt at *Tepe Hissar*, only 13 belonged to Hissar II (Bennett, 1989:127). The seals and seal-shapes from this period were similar to those from Hissar I (Schmidt, 1937:Pl.XXVIII, A). The characteristic seals from Hissar IIB were exceptionally large and made of copper with geometric design (ibid, 1933:Pl.CVII H1176, H320, 1937:Pl.XXVIII.A H2188). These seals, or their impressions, have been reported from other Iranian sites, such as Susa in Acropole I:15B and Ville Royale I:17, Godin Tepe, Proto-Elamite I horizon-from Middle Banesh, Valiyan, Tepe Yahya (IV_C), and also in surface finds from Shahr-i Sokhta, which indicates a distribution of individual items along the major trade routes across the plateau during "Proto-Elamite I" (Dyson, 1987). The Hissar II period showed great advances in both quantity and quality of copper objects. Although some simpler copper objects from Hissar I survived until Hissar II, new objects (e.g., bracelets, finger rings, and earrings) were also introduced in this period (discovered more in the graves of Hissar IIB- Schmidt, 1937:PlXXVIII,B). Schmidt (1933:Pl.CIV, C, 1937:Pl.XXIX H4856) discovered large quantities of pins with elaborated scroll heads, which seem similar to Sialk IV (Voigt and Dyson, 1992a:171). Objects such as a copper "macehead" also appeared for the first time in late Hissar II (Schmidt, 1937:Pl.XXIX H2021, H1200), and some "weapons" were also found from this period (1933:Pl.CIII, 1937:Pl.XXIX H4677, H3012- Figure 2.7). One might postulate that an association between the appearance of these objects and the evidence of destruction of the settlement in late Hissar II indicates an increase in "violence" and "stress" at that time at *Tepe Hissar*.

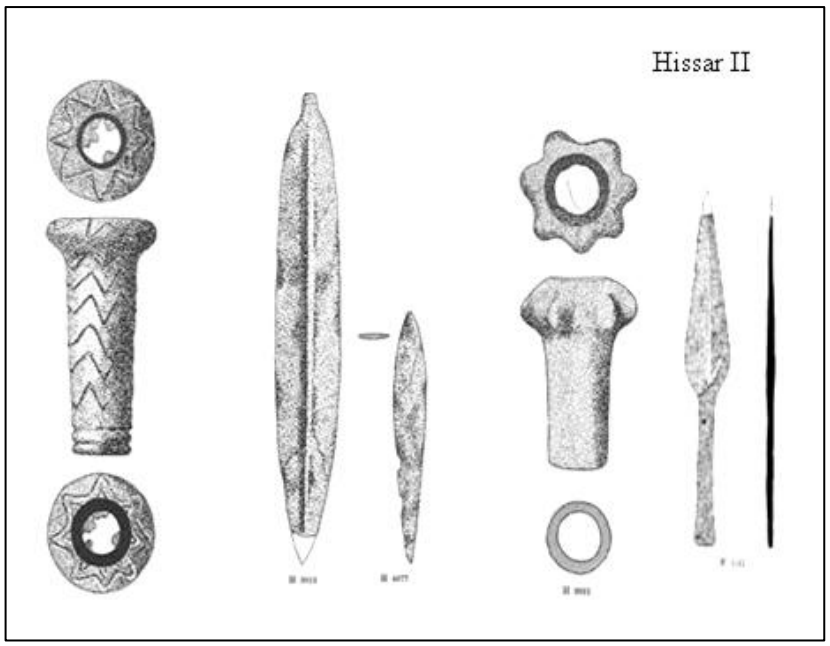


Fig 2.7. Copper mace-head (left and middle), blade (right), and dagger (middle) from Hissar II (Schmidt, 1933,1937:PL.CIII, XXIX)

Voigt and Dyson (1992a:171) indicate a similarity between some copper objects from Hissar II with Sialk IV, Tepe Yahya IV_C, Susa Acropole I:14B-15 in Iran, and Jemdat Nasr and Early Dynastic II in Mesopotamia. They suggested interaction between people during Hisser II and Proto-Elamite Susa in south Iran, and Jemdat Nasr in Mesopotamia. Precious objects of metals were still rare during Hissar II, but some silver ornamental objects, including double scroll pendants, earrings, finger rings, an oblong beads, a curious ladle-shaped pendant, and few simple ornamental gold objects, were found from this period for the first time at the site. Most of these items had copper parallels too (Schmidt, 1937:Pl.XXX, A). During Hissar IIB, however, in addition to ornamental metal objects, new semi-precious beads made from rock-crystal, lapis lazuli, turquoise, bitumen, carnelian, and alabaster appeared (ibid, 1933:Pl.CVII, B, and CVIII). Stone objects including "grinding stones", whetstones, pestles, and polishers were also discovered from Hissar II and were similar to those from Hissar I (ibid, 1937:Pl.XXXI; Horn, 1989). The discovery of grinding stones suggests that the people of Hissar II were familiar with cultivating cereals wheat (Schmidt, 1937:121), with archaeobotanical data from this period also giving confirmation (Costantini and Dyson, 1990, and see below).

The restudy team uncovered some interesting artefacts from the South-Hill (level 8-7) such as clay figurines, cones/counters, and tablets, copper smelting slag, and clay figurines which dated to early Hissar II (~ca.3700-3450B.C.-Tosi and Bulgarelli,

1989:38-34 Figures.4-6). They also uncovered similar items, including clay balls and ellipses, and cones/counters (suggesting "accounting artefacts"), from the Main-Mound-Building 2 (early-mid Hissar IIB- Dyson and Remsen, 1989:79). It is assumed that the occurrence of these small objects in early Hissar II, in addition to five pillow-shaped clay objects (between 3.5-5.5cm long), could indicate their use in a "recording system preceding writing", the "growth of an administrative organization" and "control of production" in association with "specialized crafts" in the mid fourth millennium B.C. (ibid, 1989:79; Tosi and Bulgarelli, 1989:40-41). Similar tablets and counters have been reported from the site of Proto-Elamite (Sialk) and Shahr-i Sokhta I in the Central Iranian Plateau (Amiet et al., 1978:15; Dyson, 1987).

The results of investigation of industrial debris on the surface of *Tepe Hissar* in 1976, testified that this site was an important manufacturing centre with intensive development of handicrafts and other activities during the mid 4th millennium B.C. (Hissar II). Various industrial areas showed metallurgy, semi-precious stone making (lapis lazuli, beads, soapstone, etc.), and pottery making, all of which were active simultaneously in different combination over many centuries at *Tepe Hissar* (Tosi, 1989). It had been assumed that this period correlated with the "Mesopotamia-Jemdat-Nasr" and "early dynastic" periods (ibid), although the pottery styles also indicate a correlation with the "Gorgan" region (Helwing, 2006- see above). The archaeological evidence showed a decline in metal working in mid Hissar II (IIB), being replaced by an increase in the working of lapis lazuli in the late 4th millennium B.C. (Tosi and Bulgarelli, 1989:44-50). This transition seems to be contemporary with the evidence of fire and destructions of buildings (1-4) on the Main-Mound and South-Hill. The lapis lazuli workshops at *Tepe Hissar* showed a similarity to those from Tepe Yahya IVB1. At both sites workshops were in "open areas" on abandoned structures of earlier periods and far from the main settlement (ibid:50). It seems that the people of Hissar II were active in different "specialization activities" during this period, suggesting that all the sophisticated objects found in the graves were manufactured at *Tepe Hissar* itself (Tosi, 1989:14). Nevertheless, in the early 3rd millennium B.C. the working of lapis lazuli ended, the South-Hill was abandoned and the area used as a burial ground for a short period, but it was reoccupied again with new people and a new house (Tosi and Bulgarelli, 1989:44). There was also a gap in the chronology of the Main-Mound and North-Flat at this time. The evidence shows that during periods of abandonment the whole area of each mound was used as a burial ground (Tosi, 1989- see Table 2.2).

(d) Conclusion

In the early 4th millennium B.C./Late Chalcolithic period, *Tepe Hissar* entered a new period. The technical shift in pottery, and the transition from "painted" pottery to that of the "classic grey pottery", in addition to the occurrence of clay "counters" and "tablets", "seals", a dramatic change in architectural style, and a significant increase in industrial activities, all could indicate that the site represented a complex society, which included the development of craft specialization, and an administrative system with control of production and trade during the 4th millennium B.C. (Dyson, 1987; Dyson and Remsen, 1989; Tosi and Bulgarelli, 1989:40-41). It may also be assumed that these cultural shifts at Hissar II may have influenced the demography, population admixture, diet, subsistence economy, and general health of population of *Tepe Hissar*. The evidence of frequent fires, and destruction of buildings, as well as the occurrence of weapons, however, suggest that changes, particularly in Hissar IIB, may have not been peaceful.This period finally "collapsed" in the early 3rd millennium B.C. Does this evidence indicate population replacement, invasion, or violence? Is there a lack of evidence of population continuity at *Tepe Hissar* at that time? The archaeological data overall indicate a complex dynamic of interaction between people from Hissar II and sites in the Gorgan region (Thornton, 2013).

The archaeological evidence shows that the fall of Hissar II was almost contemporaneous with the end of the Proto-Elamite period in the west and collapse of many settlements in Iran, including Tepe Sialk, Tepe Malyan, and Tepe Yahya. On the other hand, it was also contemporary with the rise of many new centres, including Konar Sandal in southern Iran near Jiroft, Shahr-i-Sokhta in the Sistan plain, in the south-east of Iran, the Umm-Al-Nasr culture in the Oman-Persian Gulf, as well as Namazga IV in southern Turkmenistan (Thornton, 2009). Masson (1988:119) suggests that at the end of 4th millennium B.C. the population of the central and northern Iranian-Plateau, including *Tepe Hissar* and the Sialk regions, moved to Kara Tepe and Geoksyor in southern Turkmenistan. Nevertheless, in the early 3rd millennium B.C. *Tepe Hissar* fell into a new era, Hissar III, perhaps due to a "dynamic force" or "foreign influence" (Schmidt, 1937:306).

(iii) Hissar III Period (ca. 2900- 1800 B.C)- The Burned Building, BMAC Culture

The Hissar III period was attributed to the Early-Mid Bronze Age (Table 2.1), where most graves contained only burnished grey pottery (Schmidt 1933, 1937). The

occupation layer thickness during this period was greater than in preceding periods, suggesting the site was smaller but more compact than during Hissar I and II. Schmidt (1937:155,306) divided Hissar III into three phases (A, B, C), but Hissar IIIB (ca.2500-2200 B.C.) is suggested to be the main phase of this period, because Hissar IIIA (ca.2900-2500 B.C.) and IIIC (ca.2200-1800 B.C.) were not as deep (see Thornton, 2009).

(a) Settlement and Building Remains- The Burned Building

There were no well preserved buildings from Hissar III, and deposits of the last phase of this period (IIIC) were destroyed by many graves from this phase (Schmidt, 1933:392). However, a few architectural remains from early Hissar III in the Treasure-Hill area showed the remains of some buildings with rectangular long and small rooms (ibid, 1937:175). In 1976, the restudy team found a series of three small rectangular ovens or hearths with central columns in the Main-Mound dated to ca.2640-2390 B.C. (Howard, 1989:68). The ovens were first reported from Hissar III buildings and found frequently in this period, but they were different to floor hearths of Hissar II. The other new characteristic architectural feature in Hissar III was the unique platform or stepped-hearth which was significant for its structure and decorative features, as well as its placement in the room (Dyson and Remsen, 1989:95-96-Figure.22). The major, well preserved and best recorded building of Hissar III is the "Burned Building" in the North-Flat area and dated by Schmidt to middle Hissar III (IIIB- 1937:157-169-Figure.91). This building had been constructed ca.2420-2290 B.C. directly on top of the previous abandoned phase IIB phase (Dyson and Remsen, 1989:91-93,108 Figure.15); was built with great care and in a more consistent style in comparison with the other buildings at *Tepe Hissar*, built with mudbrick masonry and the walls were covered with plaster (ibid:93). The building had a complex building plan with six rectangular rooms, including a main living room, some storage room, a kitchen, in addition to some other structures such as staircases, buttressed walls, a fireplace, and a tower protecting the entrance to the building (Schmidt, 1937:162-164-Figure.91; Dyson and Remsen, 1989:91,93-Figure.15). However, this building was obviously destroyed by fire. Uncovered several "charred human skeletal remains" from different parts of the building, a large quantity of "flint arrow heads" scattered inside and outside the building (Schmidt, 1937:219; Dyson and Remsen, 1989:97-Figure.24), and seven copper "daggers" from the building; suggests interpersonal violence which destroyed the

structures and killed some residents (Schmidt, 1937:164, 171). A number of valuable objects including a gold cup, a great number of lapis lazuli and chalcedony beads, and silver and copper vessels were reported from this building. Schmidt attributed it to the most important family from the Hissar IIIB period (ibid:164).

Given its unique plan and structure, the occurrence of a unique platform hearth, as well as the richness of the objects found (discs, miniature objects, figurines, alabaster columns), this building may have had a religious function at that time. It may have been some sort of small "shrine" which was in use over a considerable period of time, perhaps until the early 2nd millennium B.C. (Hissar IIIC- Dyson and Remsen, 1989:96-97,108). The restudy team reported other "burned layers", including an ash structure under the Burned Building in the North-Flat area, dated to 2420-2290B.C. The masonry style and the building method used for this building suggests that it was built perhaps earlier than the Burned Building (ibid:105). Schmidt (1937:174) found a structure such as in the form of a garden plot or courtyard on the Treasure-Hill area, and a similar structure was reported from the Burned Building. He dated these structures to Hissar IIIB. These structures had not been reported from previous periods. The architectural remains from late Hissar III suffered by their proximity and exposure on the surface and there was no well defined structural remains from this phase (ibid). Nevertheless, these archaeological data suggest that the inhabitants of Hissar III, particularly IIIB, may have experienced conflict and stress.

(b) Pottery

"Polished grey pottery" predominated in this period in addition to some types of earlier painted pottery (Figure 2.8). Schmidt (1937:155) noticed that the majority of the grey pottery was handmade, compared to the wheelmade pottery from Hissar II and their base colour was a little lighter compared to Hissar II. He also noticed that the main difference between grey wares from Hissar II and III was the "shape". The early Hissar III was called a transitional phase (IIIA) and was characterized by the occurrence of material from both Hissar IIB and IIIB. The stemmed vessel of period IIB continued into the early Hissar III period, but the typical bottle pitcher of Hissar IIIB (ibid:137 Pl.XXXVI H4755, H5218) first appears in Hissar IIIA (ibid:178 Pl.XXXVI H2070,H2164) and besides some surviving painted pottery from both Hissar II (ibid:178 Pl.XXXVI H4070, H3929).

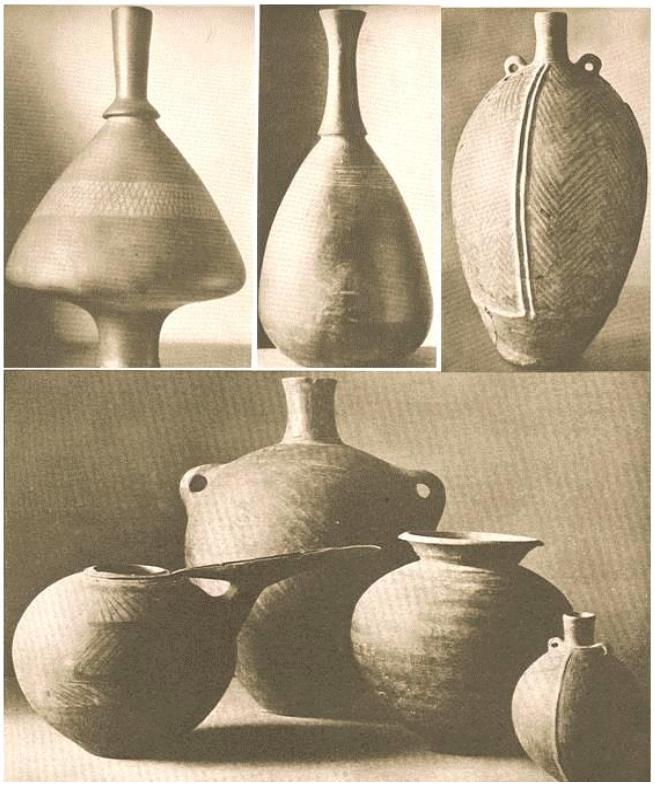


Fig 2.8. Examples of pottery from Hissar III (Schmidt, 1937:Figures 105-108)

In mid Hissar III (IIIB, mid 3rd millennium B.C.) new pottery shapes were introduced. The characteristic handmade pottery types were pear-shaped bottle pitchers with cylindrical necks, with a base of dark grey, decorated with an incised/burnished pattern of cross hatched/parallel lines or herring bone, suggesting that they originated from metal forms (Schmidt, 1933:393 Pl.CXIV, 1937:179-180-Figure.106 H3820). Furthermore, spouted vessels, bowls, and cups were also other characteristic pottery types first occurring in at Hissar IIIB. Some surviving painted pottery with geometric decoration is also reported from this phase (1937:180 Pl.XXXVII, XXXVIII, and XXXIX). Masson (1988:95) has indicated the similarity between Hissar IIIB culture and the Middle Bronze Age material from Altyn Tepe and the first hoard of that site.

Nevertheless, archaeological data show that Hissar IIIB faded into IIIC (the late phase of Hissar III) with the evidence of new forms of pottery as well as new objects, including alabaster vessels and copper *wands* (stick) in this phase (Schmidt, 1937:182 Pl.XL-XLIII). The main typical pottery types of Hissar IIIC were *canteens*: a short necked oval body bottle with two handles and a narrow perforation on both sides of the upper body; base colour was plain brown or was sometimes covered with burnished herringbone decoration (ibid:183-Figure.108 H4219). Other distinctive pottery types have been identified from Hissar IIIC, including broad mouth jars decorated with a

burnished zigzag and crosshatching pattern, bottle shaped vessels with discoid rims, spouted pitchers, and globular vessels with beautiful burnished decoration and long beaked spouts (ibid:XLI H5231, H3525, H5235, H3933, H3511). The Hissar IIIC period was defined by burnished ornamentation covering the body of some grey pottery types of this phase (Schmidt, 1937:182). However, in addition to grey ware, painted cups with linear patterns of purplish/red/brown decoration on a buff base occur in this phase, suggesting they are the last surviving pottery of earlier periods (ibid:Pl.XLIII H3305, H3312). Schmidt also indicated the occurrence of a few Plain Red-Ware vessels in Hissar IIIC mixed with the grey ware and the alabaster vessels typical of this period. Thus, he suggested the presence of these red vessels at the end of Hissar III may indicate the beginning of a "new era" characterised by red ware (ibid:308) and this may correlate with the recent discovery of Roustaei at *Tepe Hissar* (2010- Iron Age period).

(c) Other Material culture

The results of the investigations of many archaeological finds from Hissar III demonstrated intensive craft specialization, an advanced culture, and social differentiation during the mid 3rd millennium B.C. This was contemporaneous with the same development at Turang Tepe in the north-east of Iran (Gorgan region), and in Altyn Tepe in southern Turkmenistan (Masson, 1988:118). McCown (1942:54-59-Figures.17,18) indicates similarities between the material culture of Hissar III, Shah Tepe II (Gorgan region), and Anau III (Turkmenistan) during the mid 3rd to the early 2nd millennium B.C. At this time *Tepe Hissar* was occupied by specialized craftsmen smelting copper, and working interesting objects in gold, silver, lead, lapis lazuli, carnelian, turquoise, alabaster, and many other materials during the 3rd millennium B.C (Schmidt, 1933,1937). The restudy team found a number of manufacturing workshops in the southwestern part of *Tepe Hissar* which belonged to the early third millennium B.C. Tosi (1989) points out that, in these areas, different specializations such as metallurgy, stone and bone working, as well as pottery making occurred simultaneously for over a period of century. However, many archaeological materials that have been discovered from Hissar III are characteristic of this period and have not been found from preceding periods.

Animal and human figurines were more frequent in this period particularly in IIIB and IIIC and were made of various materials including baked clay, similar to those from Hissar II. However, figurines including bovine, human and animal figurines made of

alabaster, serpentine, and light yellowish brown stone was introduced in late Hissar III (IIIC) (Schmidt, 1933:Pl.CXXXIII, Pl.CXXXIV, B; 1937:186-188, 192 Pl. XLV-XLVI H2263, H2038, H2750-Figure.114H3500). Schmidt (1933,1937) indicates the occurrence of a large number of elaborate metal objects produced in Hissar III, including copper (1937:188 Pl.XLVI, HLVII H5141,H3159,H3279) and silver human and animal figurines (1933:Pl.CXXXIV H371, H370, H379), conventionalized mouflon heads of gold (1937:189, Figure.111), copper animals (1937:190 Figure.12 H2252), copper, lead, and silver vessels, spoons, pins, and jars, as well as copper disks and ornaments (1933:Pl.CXX,CXXI,CXXV,CXXIII;1937:Pl.LIII-LVIII), ornamental copper wands or sceptres (1933:Pl.CXXXI, 1937:PL.XLVIII), and many other objects, including of gold (1933:Pl.CXXII H162; 1937:212 Figure.132 H2257). The majority of these materials are seen in the Hissar III period and not in Hissar I or II. All indicate that metallurgy in Hissar III exceeded the preceding periods. The appearance of advanced forms of copper "weapons" such as bidents (two pronged weapons), knifes, maceheads, spearheads, daggers, lance blades, mattocks, and axes of a modern type in Hissar III (Figure 2.9-most frequent in Hissar IIIC- ibid, 1933:Pl.CXIX, CXVIII, CXX; 1937:Pl.l-LII, XXXIV) could indicate an increase in conflict during this period and this corresponds to other archaeological evidence such as burnt building and warriors (see below).

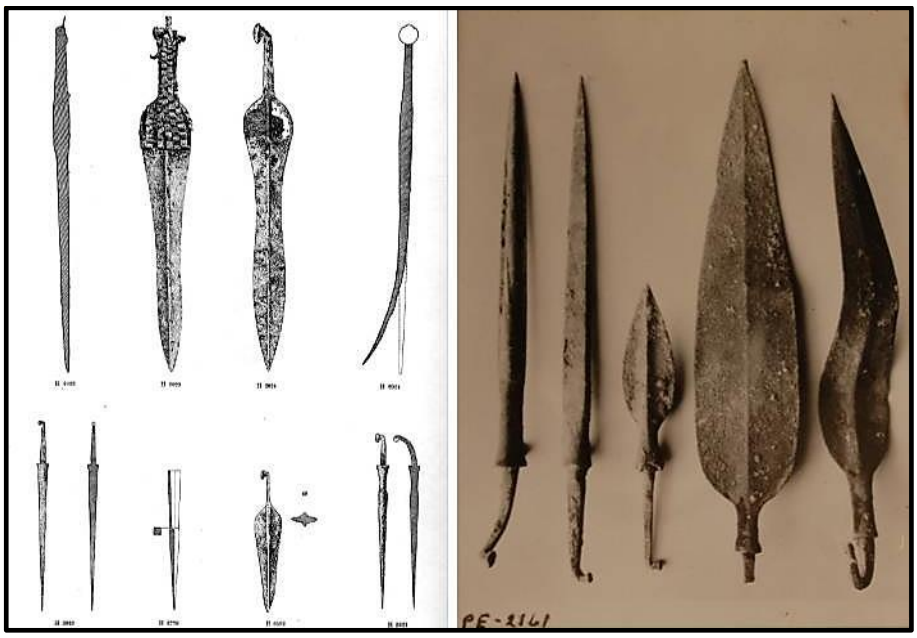


Fig 2.9. Examples of copper weapons from Hissar III (left:Schmidt, 1937:Pl.L; right:from Schmidt's unpublished archive)

The typical seals of Hissar III were stamp seals made of copper, but Schmidt (1933, 1937) discovered seals with new shapes and designs such as medallion and

cylindrical seals. The animal and human patterns were first seen on Hissar III seals, but old designs and geometric decoration was similar to the preceding period (1933:Pl.CXXIX,CXXX), suggesting continuity throughout all three periods at *Tepe Hissar* (Bennet, 1989). Schmidt indicated that three cylindrical seals were uncovered from Hissar IIIB and suggests two seals (1937:197-Figure.118 H3710, H892) have some similarity with "Mesopotamian" seals. However, seal H3710 with a "chariot" pattern was more similar to the sculpture of "Jemdat Nasr, Early Dynastic I" period. He also pointed out that seal H892 might have originated in Elamite cultural levels (1937:197-Figure.118, H116). On the other hand, he indicated its resemblance to a "Mohenjo-Daro" seal which was contemporary with those of the "Akkadian" period in "Mesopotamia" (1937:309). Dyson and Remsen (1989:79) argued that the first seal (H3710) belongs to the early Hissar III period, sometime around early third millennium B.C., and the second seal (H892) can be dated to Hissar IIIC, indicating contact with the west at that time.

Stone, which became abundant in Hissar III, was used for elaborate vessels made of alabaster which first appeared in Hissar III. Schmidt (1933:423) suggests the influence of Mesopotamia on these vessels (used for more than a millennium) and that these objects, in addition to the large copper vessels, were signs of wealth. The vessels were most characteristic of Hissar IIIC. They occurred in the form of stemmed vessels, bowls, jars, long spouted pitchers, footless plates, and decorated cosmetic jars (ibid, 1933:Pl.CXXXVI-CXXXIX; 1937:212-216 Pl.LIX-LX), but some looked similar in form to the grey pottery. Alabaster miniature columns and disks were also discovered in the "hoard" from Hissar IIIC (ibid, 1937:Pl.LXI, LXII). The evidence shows that alabaster was manufactured only in the latest part of the life of *Tepe Hissar*. Tosi (1989:24) indicates that there is less evidence for manufacturing debris of this stone in Iran except at Shahr-i Sokhta in the south-east Iran. A series of beautiful ornamental pins made of bone decorated with black incrusted parallel circles were found for the first time in Hissar IIIC (Schmidt, 1937:Pl.LXV), and objects including "mullers", "hand grinder", and "mortars" discovered from this period (1933:Pl.CXLII), suggesting that people practiced agriculture as in previous periods. Schmidt also uncovered a large quantity of attractive ornamental beads from Hissar III, including new material such as chalcedony, amber, ivory, lead and carnelian beads; carnelian is suggested as being an Indus-valley innovation. Precious and semi-precious material such as lapis lazuli,

turquoise, serpentine, alabaster, limestone, gypsum, jasper, shell, and rock crystal were all presented in large quantity from Hissar III (1933:Pl.CXLV,CXLVI).

(d) Conclusion

In the early 3rd millennium B.C. the occupation of *Tepe Hissar* continued and the site entered into the Hissar III period. The stylistic changes in pottery and metallurgy, the appearance of multifunctional activity areas (workshops), the production of large quantities of elaborate objects (e.g., precious and semi-precious metal and stone), and the appearance of new masonry techniques/architecture for the first time, all indicate remarkable cultural changes occurring during Hissar III which show many dissimilarities with Hissar II and I. The archaeological evidence shows the prosperity of Hissar IIIB and IIIC, as well as continuity in ceramic style which is suggested to have continued to develop during the mid 3rd to the early 2nd millennium B.C. (Bovington et al., 1974). The occurrence of a lapis lazuli workshop indicates that the site may have had some role in trade in lapis lazuli from its source in Badakhshan in northern Afghanistan through Central Iran to its marketplace in lowland Mesopotamia (Tosi and Piperno, 1973; Bovington et al., 1974). It may also be assumed that these changes and interaction with other regions through trade during Hissar III may have affected the structure and demography of the population, as well as their diet, and general health. On the other hand, the "Burned Building" of Hissar IIIB and discovery of "burnt" human skeletal remains, seven copper daggers, and hundreds of flint arrow heads from inside and outside of this building, as well as the discovery of "Mass Burials" and "Communal Burials" on the Main-Mound, South-Hill, and Treasure-Hill (see below), and the appearance of certain "weapon tools" (Figures 2.9-11) conflict and stress were factors in people's lives.

The data shows that in the late 3rd millennium B.C. the occupation at this site had come to an abrupt end, suggesting a "hostile invasion" from the east, contemporary with events occurring at Yarim Tepe and Turang Tepe in the Gorgan plain; however, these sites, along with *Tepe Hissar* were reoccupied by Hissar IIIC people (Schmidt, 1933:440-2; Bovington et al., 1974). It has been proposed that the occurrence of specific archaeological finds from the Central-Asian Archaeological Complex ("BMAC") culture, in the burials and hoards from Hissar IIIC (e.g., alabaster miniature columns and disks - see below) indicate movements of people from Central Asia in the early 2nd millennium B.C., suggesting Indo-Iranian movement onto the Indo-Iranian

borderland and on the Central Iranian Plateau which intended (organized-warfare) rather than trade (Sarianidi, 1981:172,189; Hiebert and Lamberg-Karlovsky, 1992; Parpola, 1998:124; Hiebert, 1998:151-155-Figure.2; Lamberg-Karlovsky,2002). However, the archaeological evidence suggests that this did not involve mass migration or a major displacement of people (Hiebert, 1998:156). This phenomenon has been attributed to a socio-political fact of extensive magnitude (Hiebert and Lamberg-Karlovsky, 1992). Nevertheless, at the end of the Bronze Age (early 2nd millennium B.C.), most sites from the Iranian Plateau, southern Turkmenistan, and the Indus-valley were abandoned for the first time in centuries (Hiebert, 1998:151). The Bronze Age settlement of *Tepe Hissar* was abandoned (Schmidt, 1937:308) at the same time as the fall of Turang Tepe and Shahr-i Sokhta in north-and south-east Iran, and Altyn-Tepe and Namazga Tepe in Turkmenistan, as well as the collapse of both capitals of the early Indus-valley civilization, Harappa and Mohenjo-Daro (Masson, 1988:135). This phenomenon has also been reported from other sites (Narges Tepe, and Pocordval Tepe) from the Gorgan region (Abbasi, 2011:22).

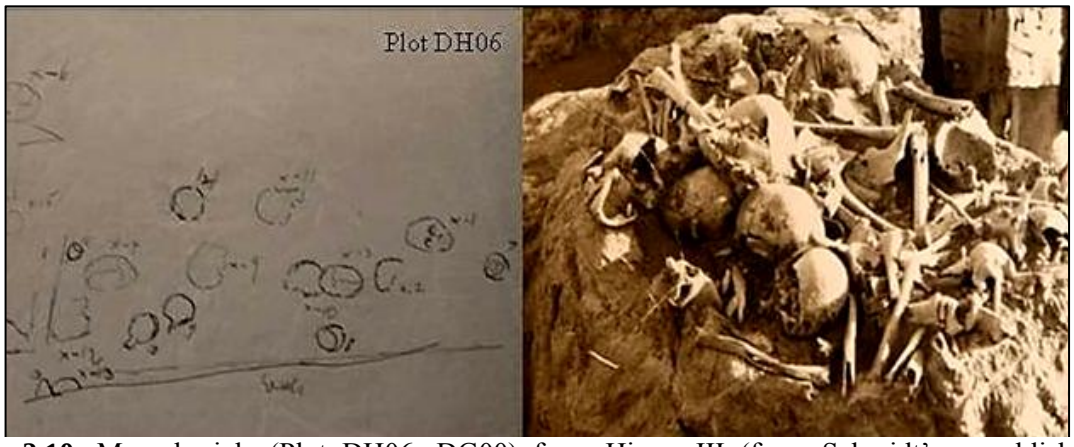


Fig 2.10. Mass burials (Plot DH06, DG00) from Hissar III (from Schmidt's unpublished archive)

Fig 2.11. Burned human skeletal remains from the "Burned Building"-HissarIII (from Schmidt's unpublished archive)

2.2.3. *Tepe Hissar* Graves

Almost 1637 burials were uncovered during Schmidt's excavations (Nowell, 1989). However, in his excavation reports of 1933 and 1937, Schmidt indicated just 782 burials from Hissar I (n=144), II (n=209) and III (n=429); but from this number he then published information on a smaller number of graves (Schmidt,1933,1937). The data regarding the rest of the burials (n=855) have not yet been published. Some of the unpublished and published burial sheets from *Tepe Hissar* are curated in Penn Museum, University of Pennsylvania and the author had access to this material for the present research.

The data show that some of the skeletons from Hissar I period had trace of "white patches" on their bones, suggesting that the deceased may had been wrapped in clothes. The dead were laid in "simple" pits. The body was buried on the right side, which persisted until early Hissar II (IIA). However, a few were on their left side, or supine, or prone (Figures 2.12-14). The hands and arms had different positions, however; in some cases they were in front of the face, suggesting fear, combat, peace, or praying. In some cases the hands were laid on the pelvis or in the pelvic aperture. The legs of the skeletons of Hissar I were flexed. The feet were pulled up, pressed down or in normal anatomical position (Schmidt, 1933:364 Pl.XCV, 1937:63-66-Figures.48-49).

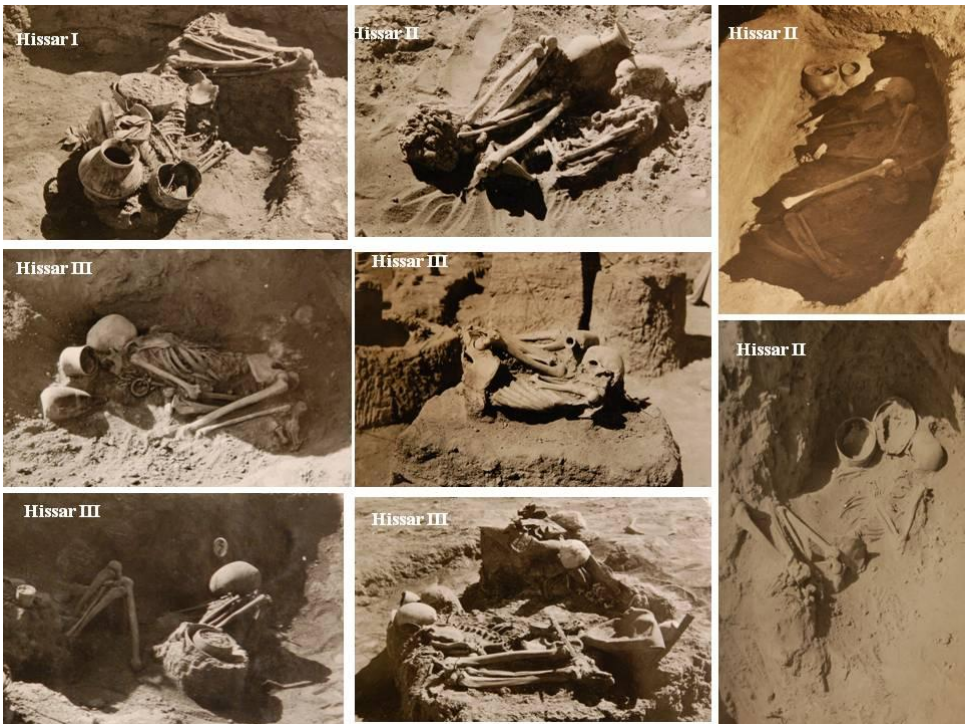


Fig 2.12. Examples of burials from Tepe Hissar (from Schmidt's unpublished archive)

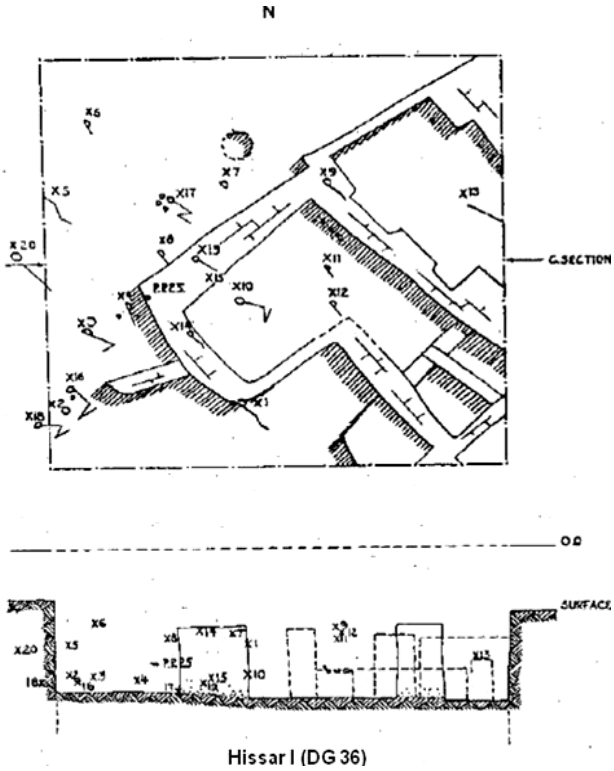


Fig 2.13. Plan and section Hissar I-buildings and burials (Schmidt, 1933:343)

The majority of Hissar I graves contained numerous grave-goods, such as painted pottery, copper pins, seals or seal shaped ornaments, and a large quantity of ornaments usually placed near the head and upper body of the dead. However, Schmidt (unpublished burial sheet) indicates that some burials were without goods during this period, and that men and women were treated similarly, suggesting the position of men was not superior to women (1937:67-Figures.50-60).

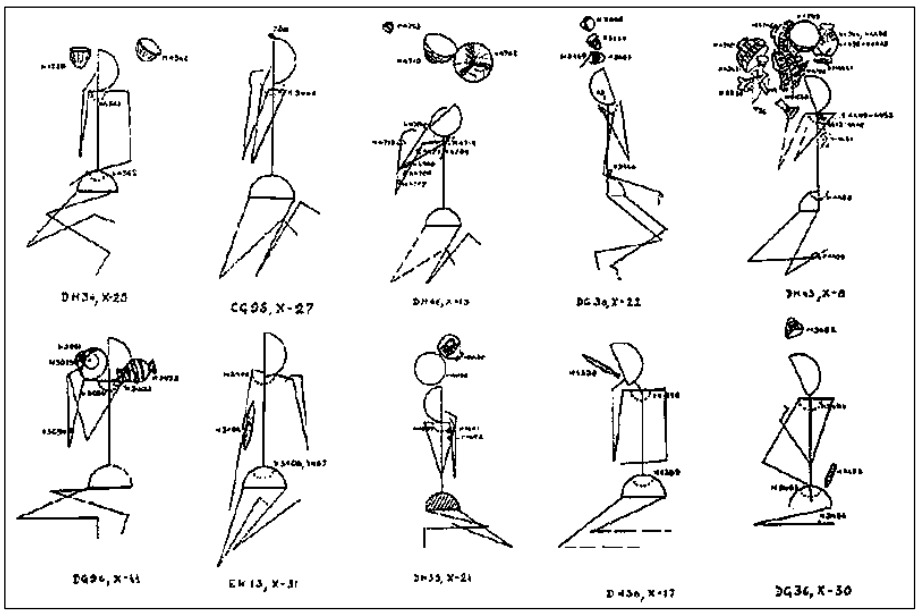


Fig 2.14. Burial schematic and grave-goods of Hissar I (Schmidt, 1937)

The dead of Hissar II were buried in "simple grave/plain earth" burials in deserted areas of the mound (Figures 2.12 and 2.15-16), or in a few cases in "mudbrick" graves; some skeletons had trace of "white" colour on the bones as Hissar I, suggesting the deceased may had been wrapped in clothes (Schmidt, 1933:389).

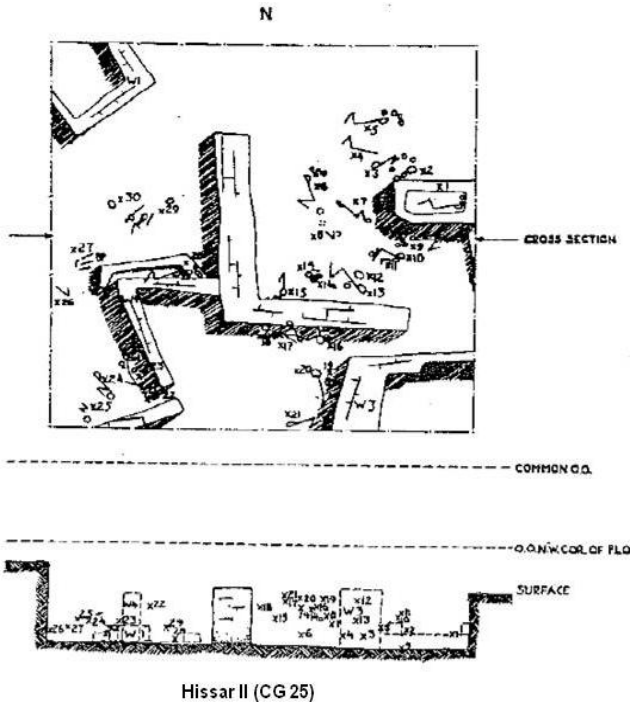


Fig 2.15. Plan and section Hissar II-buildings and burials (Schmidt, 1933:366)

In Hissar II the burial "rules" of Hissar I continued during the early part (IIA), but they changed in Hissar IIB (Schmidt, 1937), suggesting behavioural change towards the dead or a change of cult. These changes correspond to the changes in the settlement evidence, fire in buildings, and changes in pottery style, and other archaeological material. In Hissar IIB the position and orientation of the body and skull varied in some way, although the burial on the right side still survived and was evident in a great number of burials from this period II, in addition to an increase in burial on the left side, and in a supine manner. However, the position of arms, hands, and legs was still similar to those of Hissar I burials. In general, the majority of burials more or less contained grave-goods, but some had no grave-goods (Figures 2.16). In comparison with Hissar I, the grave-goods in this period were placed near the feet, chest, or other parts of the body, although in some graves they were deposited near the head and upper part of the dead body (Schmidt, 1933:385-389 Pl.CX,CXI, 1937:123-140).

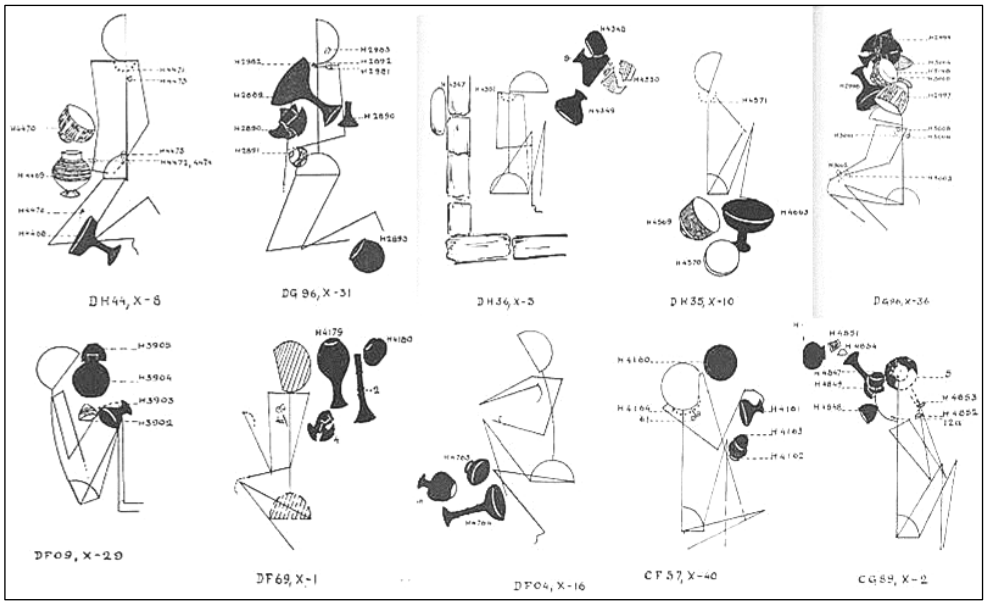


Fig 2.16. Burial schematic and grave-goods of Hissar II (Schmidt, 1937)

The people of Hissar III were buried in "plain earth" graves but in some cases a "mudbrick" grave was reported. The graves included skeletons or skulls and there were traces of "wrapping" with cloths on and below some of the skeletons, corresponding to earlier graves at this site (Schmidt's unpublished archive). Schmidt stated that in this period, the position of the body and skull was ambiguous (1937-Figure 2.13).

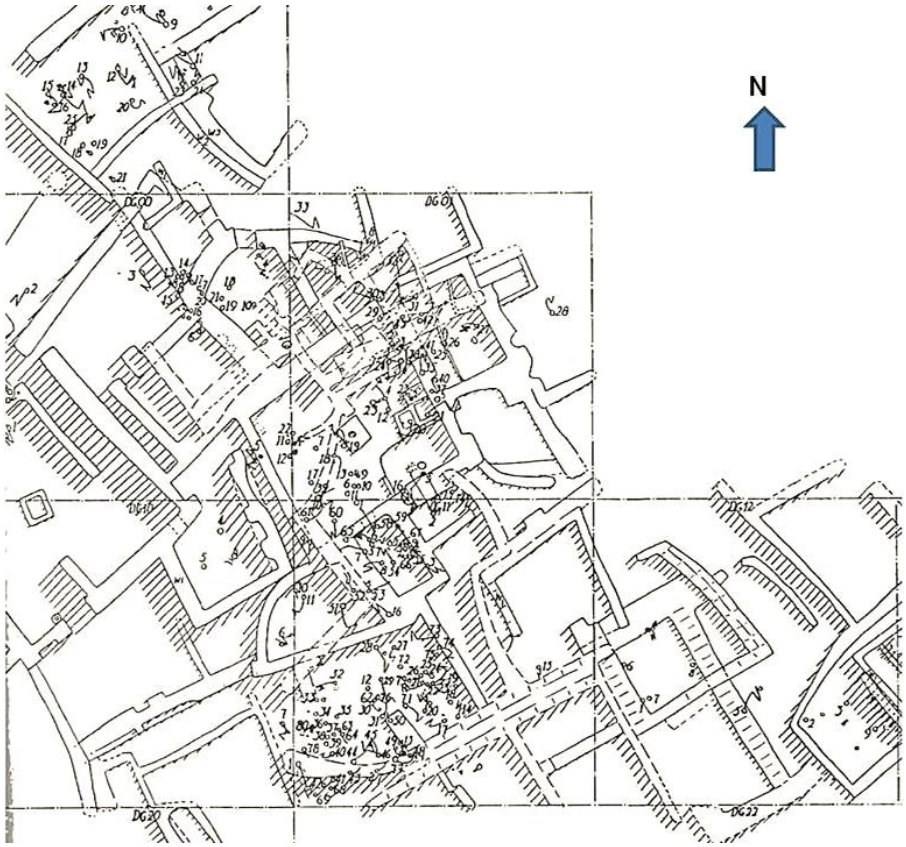


Fig 2.17. Plan and section Hissar III-buildings and burials (Schmidt, 1937:Figure.84)

The body was laid either on the right or left sides, supine or prone, or in some cases a sitting position (Figures 2.12 and 2.17-18). The arms and hands were in a different position, except the usual flexing of the legs. Some burials from Hissar IIIB were equipped with beautiful mortuary gifts such as pottery, personal ornaments, gold, silver, lapis lazuli, and weapons, and Hissar IIIC graves were equipped with alabaster vessels, metal, semi-precious stones, copper wands, seals and so forth; however, some Hissar III burials had no grave-goods, but there was no rule for the placement of goods with the body (Schmidt, 1933:442, 1937:232-238).

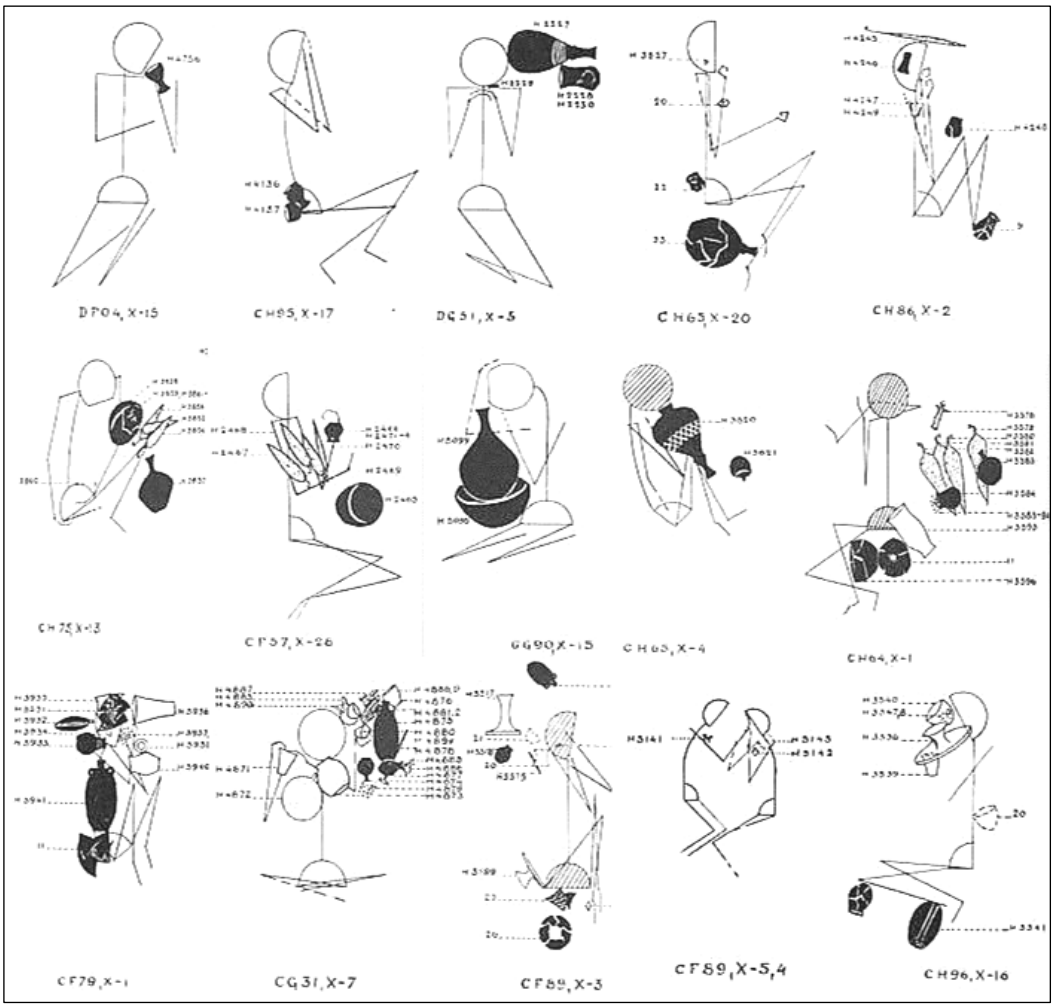


Fig 2.18. Burial schematic and grave-goods of Hissar III (Schmidt, 1937)

Schmidt (1933) also highlighted some prominent graves from Hissar III. In his "unpublished" reports ("burial sheet"), for example, he indicated that a "Communal Burial Chamber" was found in Plot DF29 in the Main-Mound. He states this 'communal burial chamber? was entered a little below floor level but not necessarily during the occupation of the building. The room was actually used as a communal burial place but several skeletons (x's)...the persona[s] were buried in S1 were not disposed of

synchronously as proven by superposition and graves disturbed by later interments.' There were 15 individuals in this chamber buried in different positions and directions, some with grave-goods and few without. Schmidt was not certain about the date of this chamber and attributed some of the burials to Hissar IIB and some to Hissar IIIB. Moreover, he indicated the discovery of interesting burials in the Main-Mound (Plot DG00), the so-called the "Mass Burial", where he found "mixed up skeletal remains" of "ten person" in a small area (Figure 2.19), suggesting these individuals had not entirely decayed before they had been deposited again, as the larger part of the skeletons were disarticulated and formed disordered bone piles (Schmidt, 1933:440). In his unpublished report Schmidt attributed this mass burial to Hissar IIIB. On the Main-Mound (Plot DG01), he also found the "second Mass Burial", similar to the first on Plot DG00, containing comingled skeletons of seven individuals in a small area (Figures 2.19-21). He attributed this burial to Hissar IIIB.

Fig 2.19. Mass burial on the Main-Mound (Plot DG00) (Schmidt's unpublished archive)

Furthermore, he (1933:440) indicated the discovery of the "third Mass Burial", or as he named it, a secondary disposal area, which included 12 to 13 individuals from Plot DG96 on the slope of South-Hill. He indicated (unpublished reports) that no skeleton was articulated and, in comparison to the number of skulls, there were not enough long bones. He attributed them to Hissar IIIB. Moreover, he reported (unpublished) the

discovery of other "Communal Burials" from Plot DH06 at Treasure-Hill which contained just nine to ten adult skulls in addition to six grave-goods (Figure 2.10); Schmidt attributed them to Hissar IIIB. However, Schmidt suggests (unpublished) that with the occurrence of Mass Burials and secondary burials one might interpret a war, massacre, epidemic, or similar catastrophe, to explain the context. However, these types of burial may simply result from long-term communal burial over many centuries. In such cases, it might be similar to mass graves in the UAE (see the site of Shimal, Vogt and Franke-Vogt, 1987) some of which may have been used by mobile pastoralists.

Schmidt (1933) also uncovered four rich burials from the Main-Mound (Figures 2.20-21). These included, "two Warriors" (DF19-X2, DF09-X1), the "Priest" (DF08-X1), and the "Little Girl" (DF18, X1), all of which suggest a social stratification and ranked society at Hissar IIIC. He attributed the Warrior graves to "Kurgans", suggesting the burial places of tribal chiefs (ibid:440-442 Pl.CXLVII). Additionally, from the Hissar IIIC ruins, Schmidt found four extraordinary rich graves, a so-called "Hoard", in the upper level of Treasure-Hill (Hoard I and Hoard II) and in the North-Flat (two hoards). They were well equipped with grave-goods including alabaster objects, weapons, copper vessels, grey pottery, human and animal figurines, as well as some ornaments such as gold and silver (1937:171-178-Figures.97, 99). These graves and their materials are identical to Central-Asian (BMAC) "Cenotaphs" also identified in Southern Turkmenistan, the Indus-valley, and Mehrgarh (Hiebert, 1998:155). The occurrence of fire in Hissar IIIB and the presence of warriors and well equipped hoards of Hissar IIIC, however, suggest that the people in Hissar IIIC may have been the invaders (Schmidt, 1937:306).

Fig 2.20. The first Warrior's grave- Hissar IIIC (DF19-X-2) (Schmidt's unpublished archive)

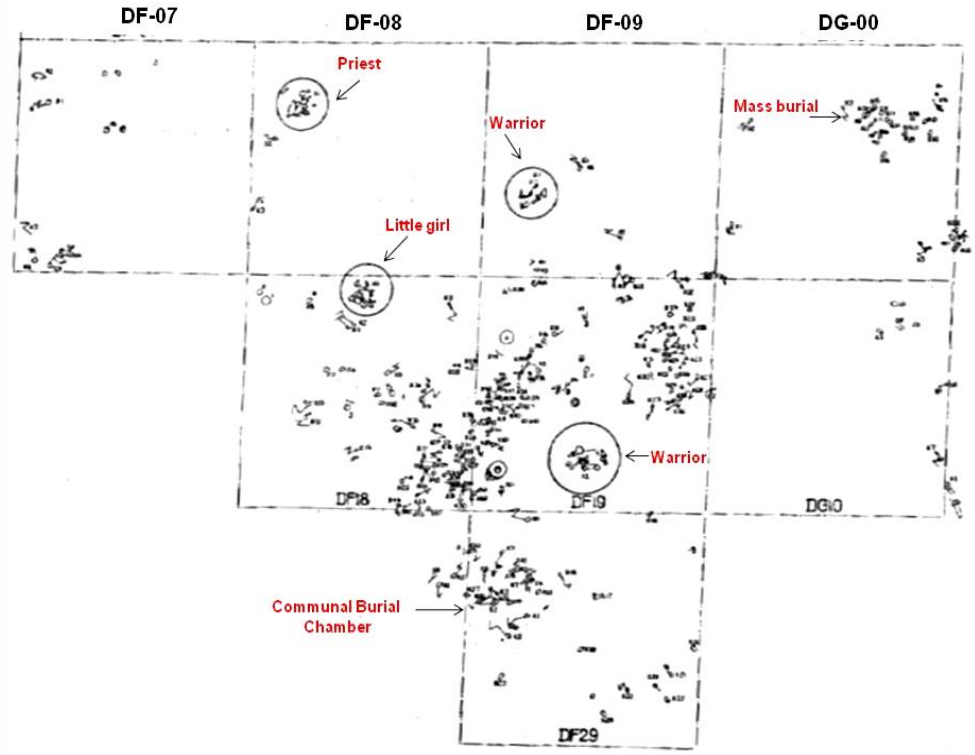


Fig 2.21. Plan of Necropolis from Hissar III, Main-Mound and four prominent graves (after Schmidt 1933:441 PL.CXLVII)

2.3. Summary

The north-eastern Iran played an important role as a "frontier zone" between the settlements of the Central Iranian Plateau and the oasis of Central-Asia. Sites around Damghan (e.g., *Tepe Hissar*), Semnan, Sari, Mazandaran, and the Gorgan plain (e.g., Tureng Tepe, Shah Tepe) were located in the east part of divided frontier. During Hissar

I much material culture, such as ceramics, architecture and technological practices, shows strong similarities to sites in the Cental Plateau such as Tepe Sialk and Arisman (Helwing, 2006). However, during Hissar II and III this sphere of influence shifts to the north and east and the *Tepe Hissar* material culture (e.g., ceramics) shows similarity to other sites in the eastern frontier and the Gorgan plain, and to the Central-Asian Namazga Culture and Sumbar-Valley of western Turkmenistan; this is entirely different to contemporary material culture of the northern frontier (Khorasan) (see Helwing, 2006; Thornton et al., 2013). There is a minor evidence showing a connection with Proto-Elamite horizons or the Late Uruk at that time, although other sites of the north Central Iranian Plateau (e.g., Qazvin, Kashan and Tehran Plains) show strong connections to the early Proto-Elamite horizons (Thornton et al., 2013). In late Hissar III, archaeological materials of the early BMAC (Namazga V, 2200–2000 B.C., e.g., grooved stone columns, trumpets) appeared at all the sites in the Gorgan region (e.g., Tureng Tepe, Shah Tepe), but there were also some non-BMAC artifacts (e.g., stylized female figurines made from stone plates) discovered from Hissar IIIC (see Thornton, 2013). Nevertheless, the frontier region has long been a dynamic cultural landscape where diverse groups of people interacted in various ways. The archaeological record suggests diachronic movements of ideas, trends, technologies, and people between the Central Iranian Plateau and southern Turkmenistan through this critical frontier zone; however, the movement of pastoralists across this landscape today raises a number of intriguing possibilities of relevance to these traditional patterns of migration and trade (ibid, 2013).

The following chapter outlines the metrical and non-metrical trait analysis of skeletal and dental remains to determine biological affinity within and between populations from the three *Tepe Hissar* periods.

Chapter 3 : BACKGROUND 1: NORMAL VARIATION- SKELETAL AND DENTAL EVIDENCE AND QUESTIONS OF BIOLOGICAL RELATIONSHIPS

The chapter provides a brief outline about skeletal and dental metric and non-metric traits analyses and their importance in biological distance studies in past populations. The current research utilized these methods to assess biological distance between the Chalcolithic and Bronze Age (late 5^{th}- 2^{nd} millennium B.C.) populations at *Tepe Hissar* in order to understand their biological relatedness.

Rather than relying on material culture to make inferences about the biological relationships between humans, it is suggested that human skeletal and dental remains can provide the most valuable direct evidence for investigating this aspect of past populations (Buikstra and Ubelaker, 1994:69; Pietrusewsky, 2008:487). Biological distance analyses (or biodistance studies) measures the relative similarity between human groups based on "phenotypic" data from the skeleton (Larsen, 1997:302). The combination of this phenotypic data with archaeological context information can be used to address many archaeological questions and elucidate patterns of relatedness, divergence, and whether there is any evidence for migration of populations into an area (Buikstra et al., 1990; Conner, 1990; Larsen, 1997:304). Based on neutral theory (Harvati and Weaver, 2006; Roseman and Weaver, 2007) it is assumed that "phenotypic" variation is a reflection of "genotypic" variation within populations. This variation is considered consistent among groups, and therefore the more similar phenotypic traits are between two groups the more closely they are suggested to be genetically related (Larsen, 1997:302; Stefan and Chapman, 2003). In the recent past, biodistances have been used more frequently in the analysis and reconstruction of past population structures, rather than to explore racial typology that characterised earlier studies (Jantz and Owsley, 2001; Relethford, 2001, 2004a). These studies have investigated evolutionary history, gene flow, social groupings, genetic relatedness within or between past populations, the presence of individuals from other populations, and many other isolating mechanisms regarding human biological relatedness (e.g., Buikstra et al., 1990; Larsen, 1997:304; Lahr, 1996; Jantz and Owsley, 2001; Relethford, 2001, 2004a-b; Herrera et al., 2014). Biological distance studies in bioarchaeological research are routinely based on measuring bones and teeth (quantitative), and recording non-metric traits (qualitative), because they have a genetic

basis and can provide an indirect reflection of genetic variation within and between populations (Susanne, 1977; Cheverud et al., 1979; Carson, 2006a-b; Pietrusewsky, 2008:487; Smith, 2009; Konigsberg and Ousley, 2009).

3.1. Metrical Analysis of Skeletal and Dental Remains (population affinity)

Osteometrical (measurements of bone), and odontometrical (measurements of teeth) data are perhaps the most fundamental data in bioarchaeological studies and they play an important role in the understanding of normal skeletal and dental variation among individuals and human groups (Pietrusewsky, 2008:487; Mays, 2010:91). Researchers have defined hundreds of standard anthropometric landmarks on the skeleton, including the skull, although dental measurements are not defined in terms of anatomical landmarks (Mays, 2010:95). Measurements taken between anatomical landmarks on bones characterize the size and shape of the component parts of the skeletons of individuals (Bass, 1995:62; Larsen, 1997:305). In addition to individual measurements, standard indices (the ratio of one measurement to another) define the shape and size of certain craniofacial components as well as teeth and areas of the postcranial skeleton (Brothwell, 1981:87; Bass, 1995:69-79). There are limitations in the recording and interpretation of measurements; e.g., factors such as surface damage and post-mortem breakage of bones or teeth may make some measurements inaccurate or prevent some measurements being taken (Brothwell and Zakrzewski, 2004:27). It is also important to note that measurements must be taken to and from the correct and defined anatomical points and landmarks to allow effective interpretation and also comparisons between studies (Bass, 1995:61). Therefore, researchers should be aware of these limitations and measure complete/undamaged parts for bones and teeth.

Measurements of the skull and tooth crown are commonly taken using two methods: manual measurement by using sliding callipers, spreading callipers, and a tape measure (Brothwell, 1981:78; Bass, 1995:9), and geometric morphometric analysis, which are a recently developed alternative method (Hennessy and Stringer, 2002; Slice, 2005; González-José et al., 2008; Smith et al., 2009; Mays, 2010:95; El-Zanaty et al., 2010; Ashar et al., 2012). However, the manual method is still widely used and remains an important research tool today, because callipers are relatively cheap, have the advantage of being simple to use, and are portable for fieldwork. Metrical analysis provides an important source of information about variation within and between human populations in time and space; it can help with age and sex-estimation, stature

calculations, and is one of the most notable contributions to science of the discipline of physical anthropology (Pietrusewsky, 2008:487). In investigating population structure and past human relationships, however, metrical analysis is popular and has a long history of study (Stojanowski and Schillaci, 2006; Pietrusewsky, 2008:488).

3.1.1. Craniofacial Measurements

(i) The History of Craniofacial Studies

It has long been noted that human populations across the world vary greatly in craniofacial morphology (Howells, 1973, 1989; Smith, 2009), and its study show that it can be used to interpret human population history (Harvati and Weaver, 2006; Hubbe et al., 2009; Relethford, 2009). Metrical studies of craniofacial variation are widely accepted as a key resource in identifying relationships between different populations, and understanding the nature of migrations of people in the past (Buikstra and Ubelaker,1994:69; Larsen, 1997:305; Mays, 2010:91).

The history of craniofacial studies goes back to the beginning of the eighteenth century, when physical anthropologists relied on craniofacial morphology to classify human groups, and to investigate population history (Larsen, 1997:226). The first attempt to define skull shape was based on the "cranial index", first described by Anders Retzius in 1860 (Lasker, 1994:2). Using the ratio of the length to the breadth of the skull, he classified human skulls into three main categories: "Dolichocephalic" (long, narrow skull), "Brachycephalic" (short, round skull), and "Mesocephalic" (intermediate between long and round skull) (Coon, 1939:256; Lasker, 1994:2). In 1875, Paul Broca defined a number of systematic landmarks to be used in taking measurements, and the measurements to be taken for craniofacial analysis (cited by Penniman, 1965:87). In 1914, Rudolf Martin first introduced the classic definition of cranial landmarks (cited by Lasker, 1994:2) and these were latere developed into a complete definition of the landmarks and measurement techniques (Bass, 1995; Brothwell, 1981; Buikstra and Ubelaker, 1994), which are still used today in many studies. During these formative periods and typical of the discipline most studies explored "racial" history and classification (Pearson, 1926; Pietrusewsky, 2008:487). Blumenbach (1752-1840) classified the human skull into five different races including: "Caucasoid", "Asian", "African", "Malay", and "Americans". This was accepted as the most influential and used classification up until the first half of the nineteenth century (Coon, 1939:280; Penniman, 1965:45). This and similar classifications were used by a series of scholars

such as Samuel George Morton to correlating cranial capacity with intelligence in 1849 (Gould, 1978; Lieberman, 2001). William Z. Ripley classifying Europeans into "Europeans-Nordic", "Mediterranean", and "Alpine" (Ripley, 1899) and Carleton Coon (1939) in his book *The Races of Europe*. Nevertheless, the early craniofacial studies and classification of individuals into different races and groups based on features of skull are now seen to have little value (Roberts, 2009:142).

During the 20th century, there was a major development with the introduction of new theories, methods, and multivariate statistical techniques for analysing craniometrical data and making population comparisons (e.g. Howells, 1969, 1973, 1989; Mays, 2010:108). Racial types were abandoned, and there was a shift to study the nature of family resemblance, measures of distance between populations, within population heterogeneity, migration, and the role of inheritance and genetic components in craniofacial growth and morphology; these are now the major focus of research (Wylie, 1944; Kraus et al., 1959; Horowitz et al., 1960; Vandenberg and Strandskov, 1964; Howells, 1973, 1989; Spence, 1974a-b; Susanne, 1975,1977; Pietrusewsky, 1990, 1994, 2006; ; Key and Jantz, 1990; Kohn, 1991; Key, 1994; Hanihara, 1996, 2006; Powell and Neves, 1999; Jantz and Owsley, 2001; Relethford, 2001, 2004a-b; Schillaci, 2003; Hemphill and Mallory, 2004; Stojanowski and Schillaci, 2006; Stynder et al., 2007; Kozintsev, 2009; Pinhasi and von Cramon-Taubadel, 2012).

Many different methods have been employed to study craniofacial morphology among populations (Kohn, 1991). Because of the often highly irregular shaped skull, certain international accepted "cranial landmarks" have been defined. Craniofacial metrical analysis measures between these "landmarks" to assess the skull's size and shape (Brothwell, 1981:80-2; Buikstra and Ubelaker, 1994:69-78; Mays, 2010:92 Figures 4.2-5). In early genetic studies, craniofacial morphology was modelled by numerical estimates of the distances between the landmarks identified on radiographic images (Nakata et al., 1976; Kohn, 1991). Since then, these relevant standard landmarks have been used in the majority of craniofacial studies of populations, using both linear measurements and geometric morphometric techniques (Howells, 1989; Relethford and Harpending, 1994; Lalueza Fox et al., 1996a; Hennessy and Stringer, 2002; Slice, 2005; González-José et al., 2008; Mays, 2010:95). There have also been many attempts to apply statistical procedures to evaluate craniofacial shape and size (Pietrusewsky, 2008:488). Multivariate statistical analyses mostly used in bioarchaeological studies include principal component analysis (PCA), factor analysis, discriminant function

analysis, as well as mahalanobis generalized distance (d^2). The results of these analyses are then visualized using different clustering and multi-dimensional methods (Pietrusewsky, 2008:492). These statistical procedures are well suited to biological distance studies in investigating inter-relationships between measurements, examining population differences, and for the interpretation of internal or external influences among populations (ibid:490).

(ii) Factors Influencing Craniofacial Morphology

It is becoming clear that the differences and degrees of variation in craniofacial shape and growth in human populations are a result of complex factors (Smith, 2009) including "genetic" and general epigenetic and "environmental" components (Beals, 1972; Kohn, 1991; Lalueza Fox et al., 1996a; Larsen, 1997:227; Mays, 2000b:278; Hubbe et al., 2009).

(a) Non-genetic or environmental factors

The morphology of the cranial vault has been argued to be influenced by environmental factors, since the skull has a high degree of plasticity (Kohn, 1991; Roseman and Weaver, 2004; Harvati and Weaver, 2006; Betti et al., 2010). Poor nutrition during the years of growth and development may result in flattening of the base of the skull in an adult (Angel, 1982; Mays, 2010:96). Factors such as age and sex are important determinants of skull form, but direct mechanical pressure on the growing skull, such as artificial cranial deformation through binding, and some diseases such as hydrocephalus may also influence skull shape (Kranioti et al., 2008; Mays, 2010:95). Therefore, skulls with artificial deformation and disease are not valuable in craniometric studies. Diet and mechanical factors such as those related to masticatory, non-masticatory functions, and climate also influence cranial shape (Beals et al., 1983; Larsen, 1997:305; Mays, 2000a:80; Sardi et al., 2006). For example, changes in diet and subsistence pattern with the introduction of agriculture and access to softer foods, led to a decrease in mechanical loading of the face and jaws, resulting in a less robust, shorter and rounder skull (Larsen, 1997:232-3). Some authors have also reported a highly significant association between climate and craniofacial morphology. Cranial breadth measurements (indicating a brachycephalic cranium) have been suggested to be an adaptation to a cold climate (Beals et al., 1983). Facial height, facial breadth, and nasal dimensions are also suggest to be related to climate and temperature (Roseman, 2004;

Roseman and Weaver, 2004; Harvati and Weaver, 2006; Hubbe et al., 2009). Nevertheless, some studies have found no association between climate and craniofacial morphology (Sparks and Jantz, 2002; Betti et al., 2009, 2010).

(b) Genetic factors

Despite the influence of non-genetic factors on human craniofacial form, family studies of human populations based on craniofacial measurement comparisons among triplets, siblings, between identical twins, and parents' offspring have provided considerable information about the effect of genetic and epigenetic factors on craniofacial morphology (Wylie, 1944; Kraus et al., 1959; Horowitz et al., 1960; Harris et al., 1973; Susanne, 1975, 1977; Nakata et al., 1976; Cheverud et al., 1979; Kohn, 1991; Larsen, 1997:305; Sparks and Jantz, 2002; Arya et al., 2002).

Morphological variation in the skull has been used on a global scale, to evaluate genetic variation within and between populations (Relethford and Harpending, 1994,1995; Relethford, 1994,2001, 2002, 2004a-b, 2009,2010; Roseman, 2004). The results of these studies indicate that the factors affecting craniofacial measurements (as reflected both by traditional linear measurements and by geometric morphometric data) are very similar to those obtained from studies of DNA data (Mays, 2000b:279; Relethford, 2002, 2004,2010; Roseman, 2004; Roseman and Weaver, 2004; Manica et al., 2007; Betti et al., 2009; Smith, 2009). For example, Herrera and colleagues (2014) found a high correlation between cranial and dental metrical and non-metrical data and mtDNA and Y-chromosome data. Smith (2009) studied 83 craniofacial landmarks in 14 modern human populations, using three dimension analyses. He reported that facial morphology demonstrated the highest correlation with molecular distance, reflecting genetic relationships. Other studies show a strong association between craniofacial morphological variation and geographic distance between human populations (Hubbe et al., 2009). This means that human groups that are farther apart from one another will tend to be less similar than those that are closer to each other (Roseman, 2004; Relethford, 2004, 2009; Harvati and Weaver, 2006; Smith et al., 2007). This is similar to studies of classic genetic markers (Relethford, 2010). Thus, there is a high degree of genetic control of craniofacial measurements and, in the absence of genetic information, however, craniometric data can serve as a useful substitute for investigating biological distance between individuals, and between human groups in the past (von Cramon-Taubadel and Weaver, 2009; Mays, 2010:124; Pinhasi and von Cramon-Taubadel,

2012). Nevertheless, environmental influences (diet, nutrition, climate, etc.) and genetic factors should be considered simultaneously when craniometrical studies are being undertaken in biodistance studies of ancient populations.

(iii) Craniofacial Metric Variation and Past Population Studies

Cranial metric studies have made a major contribution to biodistance studies in archaeology (Hemphill, 1998,1999a-b; Mays, 2000b:279; Zakrzewski, 2007; Hanihara et al., 2008; Ross et al., 2008; Keita and Boyce, 2008; Kozintsev, 2009; Ousley and Jones, 2010). For example, Pinhasi and Pluciennik (2004) studied craniofacial morphology in 231 individuals from three Mesolithic and Neolithic sites from the Middle East, Anatolia, and Europe. Their hypotheses interprets that Neolithization in Europe followed the migration of Near Eastern farmers to many areas of Europe, replacing local hunter-gatherer groups with only a minimal to moderate amount of admixture. It is also suggested that this transition was a sociocultural process which did not involve such large scale population changes, with the spread of farming being gradual and not necessarily resulting in a major break in a mobile hunting-gathering lifestyle. The authors suggest that there was considerable morphological heterogeneity among the earliest farmers of the Levant from the Pre-Pottery Neolithic period; however, that similarity was not seen among the earliest mainland farmers of south-eastern Europe, suggesting a largely exogenous origin for many early Neolithic populations in this region. Moreover, the data show a similarity between the farmers of mainland Europe and those from Çatal Höyük (central Anatolia). The mainland farmers likely entered Europe through western Anatolia, but the biological profile of these early farming populations differed from that of local hunter-gatherers. Another example comes from Stynder (2009) who studied craniometrical variation between 138 individuals from Later Stone Age herders and hunter-gatherers from South Africa. The study investigated the biological distance between these populations using metrical data to test the archaeological hypothesis that the herders changed the nature of the hunter-gatherers economy. The craniometrical data indicated that South African Later Stone Age hunter–gatherers and herders had different socio-economic components and were a single genetically defined population. A final example comes from Kozintsev (2009) who measured 220 male Neolithic and Bronze Age crania from Eurasia, Ukraine, Central and Western Europe, and the Near East. Archaeological data suggested that migrants from the Near-East played a major role in the origin of Southern Siberian

cultures in the Bronze Age. This was supported by the data indicating that all gracile Caucasoids were from the Mediterranean region. The study showed that none of the Caucasoid skulls from Siberia and Eastern Central-Asia were "Mediterranean", but that they were Nordic.

(iv) Contribution of Craniofacial Metric Analysis to the Study of Ancient Iranian Population History

The earliest description of Iranian (Persian) cranial morphology goes back to 445 B.C. and Herodotus (Field, 1939a). Herodotus states that 'on the field where this battle was fought I saw… the bones of the slain lie scattered upon the field in two lots, those of the Persians in one place by themselves.., those of the Egyptians in another place apart from them: If, then, you strike the Persian skulls, even with a pebble, they are so weak, that you break a hole in them; but the Egyptian skulls are so strong, that you may smite them with a stone and you will scarcely break them in.' (ibid:40).

The history of modern craniometrical studies in Iran goes back prior to the First World War. In the early twentieth century the concept of an "Aryan race" was the subject of much debate and was used in political propaganda in Europe (Wilber, 1975:163; Abdi, 2001). European "nationalism" and the "Aryan theory", however, motivated many European archaeologists, historians and anthropologists to trace the ancestors and origin of European populations in ancient Iranian and south-western Asian cultures and populations (Field, 1939a-b; Coon, 1939; Ghirshman, 1977; Fazeli, 2006:33). They attempted to classify modern Iranian populations into different "racial" groups, comparing them with populations of Southwest Asia to reconstruct true "racial" histories of the area (Field, 1939b:432; Field, 1951). In 1899, Ripley published *The Races of Europe: A Sociological Study*, indicating Iranian "racial" types and comparing them with populations from south-western Asia. He states that Iranians were a "Mediterranean" race and represented the oldest population in the world (1899:443-452). In the early twentieth century, the King of Iran, *Reza Shah Pahlavi* (1925-1941) was partly inspired by European nationalism. The ancient past, the Persian language, and the ancient people of Iran were of vital importance for him to provide a political legitimacy for his dynasty. In 1938, he founded the Centre for Iranian Anthropology and soon after that the Museum of Iranian Anthropology and the Museum of ancient Iran. *Reza Shah* strongly encouraged and supported archaeological and anthropological studies in Iran, bringing back to life the memory of a "pure Persian", claiming "Aryan"

inheritance, and he changed the country's international name from "Persia" to "Iran" to reflect its Aryan heritage against Islamic understandings of Iran (Abdi, 2001; Fazeli, 2006:33, 2009:77; Jenkins, 2012). Nevertheless, during this time anthropological studies of Iranian populations were considered a significant branch of knowledge for Iran because of the perception of the Aryan race. This was because European scientists believed Aryan was among the noblest races, and Aryan was felt to equal Iranian (Fazeli, 2006:48).

In 1939, Henry Field in his book *Contributions to the anthropology of Iran* tried to highlight the racial origins of the modern inhabitants of Iran, particularly from the Iranian-Plateau, by tracing the ancestors of European people using craniofacial morphological studies of modern and ancient populations from different regions in Iran. He stated that the first inhabitants of Iran were the "Mediterranean" race, and later the "Nordic" race entered Iran (Field, 1939a:507; Field, 1939b:516-521). His survey in Iran was to continue the anthropometric survey of south western Asia which he had already begun in 1928 (1939a:7). However, in that time Carleton Coon (1939:86,415-422) attempted to trace the "racial history of the European populations". Coon in his book *The race in Europe*, based on craniometrical data, described the "racial" type of modern and ancient Iranian populations as well as other regions. He states that the 'physical anthropological survey of early Iran and Iraq is of value in the larger problem of the "white race" (Aryan race), for it enables us to define clearly the physical characteristics of the Mediterranean types of man which were responsible for what may have been the world's earliest civilization, and of the surrounding regions.' (1939:91). He also attempted to identify the "Nordic racial complex of Europe", and stated that the "Nordic" people had been "racially" related to the inhabitants of the Iranian-Plateau in the past (ibid:240).

Nevertheless, the earliest craniofacial studies on human skeletal remains uncovered from archaeological sites in Iran were based on "racial" classification. Special attention was paid to the use of the cranial index, which at that time was considered a well established measure (e.g., Ghirshman, 1938; Fürst, 1939; Krogman, 1940a-b; Rathbun, 1972). For instance, Fürst (1939) states that the examination of skull-types showed that the Bronze Age inhabitants of Shah Tepe in the southern Caspian Sea area in Iran belonged to the "dolichocephalic" and "mesocephalic" types. Krogman (1940a-b) published both *Racial types from Tepe Hissar, Iran, from the late fifth to the early second millennium, B.C.* and *The peoples of early Iran and their ethnic*

affiliations. He studied "racial" types in Chalcolithic and Bronze Age human skeletal remains from *Tepe Hissar*, and reported that the Hissar population were "Mediterranean", "Proto Nordic", "Alpine" and "Negroid" types. In 1973, Mario Cappieri published *The Iranians of the Copper/Bronze Ages*. He used metrical data for analysis and comparison of variation in six Chalcolithic and Bronze Age populations that included: Choga Zanbil near Susa, Luristan (Tepe Giyan, Tepe Jamshidi, Tepe BadHora), Hasanlu near Uromiyeh, Shah Tepe south of the Caspian Sea, and Tepe Sialk and *Tepe Hissar* in the Central Iranian Plateau. He found a relative uniformity and homogeneity in the populations from these areas during the Chalcolithic and Bronze Ages, although the geographical distance between these settlements is considerable (Cappieri, 1973). In 1975, Rathbun studied 14 Southwest Asian populations using multivariate metrical analysis. He found that the craniofacial morphology of *Tepe Hissar* males was closely affiliated to groups from India and Turkmenia, while females showed close biological affiliation to females from Hasanlu IV in northwest Iran, Anatolia, and Kish in Iraq. He concluded that the males appeared to show "localized tendencies", while females were more homogenous (cited in Rathbun, 1989:133). In 1979, he studied variation in metrical and non-metrical data among Southwest Asian populations from seven sites in Iran and Iraq, but the data supported the earlier metrical analysis (ibid:473). Later in 1982, Rathbun also investigated biological distance among Southwest Asian populations (3500-200 B.C.), including Kish, Al 'Ubaid and Ur in Iraq, and Hasanlu, *Tepe Hissar* and Dinkha Tepe in Iran, using multivariate analysis. Nevertheless, these older and more traditional physical anthropological data are the only sources available for comparative ancient population studies for many archaeological sites in Iran today.

However, in more recent years there have been further studies by Hemphill (1998, 1999a-b; Hemphill and Mallory, 2004). In his studies, he compared craniofacial morphological variation among the Oxus Civilization inhabitants of the North Bactrian Oasis of Southern Uzbekistan with Bronze Age samples from Iran and the Indus-valley, with the aim of tracing the origin of the Oxus Civilization populations. The data yielded a pattern of biological affinity between north Bactria and Iranian-Plateau samples, indicative of gene flow. In 2006, Afshar compared craniofacial variation in Bronze and Iron Age Iranian inhabitants from Shah Tepe, Tepe Hissar, Gohar Tape, and Dailaman with North Bactrian populations. The data failed to show close relatedness between inhabitants of Bronze Age Northern Iran, but showed close morphological similarity

between the Bronze Age inhabitants from Hissar III and the Iron Age inhabitants from Dailaman in the South West Caspian Sea. Similarity was seen between Bronze Age Iranian and north Bactrian samples (Afshar, 2006).

3.1.2. Dental Measurements

(i) The History of Dental Metrical Studies

Tooth size presents important information about evolution, heritability, gene flow, and adaptation. It is a valuable tool in understanding population structure and history, as well as biological relationships between individuals and human groups (Scott and Turner, 1988; Larsen, 1997:306, 245; Jacobi, 2000:59; Herrera, et al., 2014). The study of tooth size goes back to the late nineteenth century when dental studies entered anthropological consciousness in a significant way. Scholars started paying attention to variation in tooth size and shape among fossil and modern human groups (Kieser, 1990:31; Scott, 1997:335). Other studies of dental measurements also dealt with comparative "racial" variation and classification, and attempts were made to associate certain characteristics of teeth to "racial" origins of populations under consideration (Flower, 1885; Shaw, 1931; Nelson, 1938; Alt et al., 1998:24). Flower (1885) in his paper *On the Size of the Teeth as a Character of Race* argued that the teeth of certain races have different sizes. According to the size of teeth, he divided human "races" into "microdont" (Caucasian or white "races"), "mesodont" (Mongolian or yellow "races"), and "megadont" (black "races" and Australians).

However, it was in the early twentieth century that scholars of evolutionary biology, dentistry, and physical anthropology began to rely on odontometry as additional data that could provide insights into biological affinity and dissimilarity between human groups (Shaw, 1931; Nelson, 1938; Kieser, 1990:31; Scott and Turner, 2008:12). In 1923, Hrdlička, who was the pioneer of dental anthropology, measured the dimensions of first and second lower molars of fossil and living great apes and modern humans to investigate their relationships (1923a-b; Scott, 1997:335). During the 20th century, following theoretical developments and evolutionary synthesis and advances in scientific disciplines, scholars were encouraged to think more about the "genetic" basis for tooth size, and less about "racial" typology and classification (Bailit, 1975; Alt et al., 1998:16,23; Scott and Turner, 2008:12). However, since gaining a better understanding of the hereditable nature of tooth size, many researchers have paid more attention to dental genetic research and human dental variation as a means of exploring relationships

and migratory patterns of human populations (Moorrees, 1957; Horowitz et al., 1958; Brothwell, 1963; Townsend and Brown, 1978a, 1979; Lukacs, 1981, 1985; Bhasin et al., 1985; Scott, 1997:337; Hanihara and Ishida, 2005; Matsumura and Hudson, 2005; Matsumura, 2006; Townsend et al., 2012).

From the early studies of tooth size, scholars attempted to design standard methods for taking dental measurements, since standard methods aid accurate comparison of tooth size between and within groups and subgroups (Mayhall, 2000:110). In 1923(a,b), Hrdlička attempted to standardize dental measurement techniques, but he did not provide a monograph devoted to teeth (Scott, 1997:336). Since then, various methods of dental measurements have been applied to capture tooth size and attempts have been made to design standardized measurement techniques and terminology (Shaw, 1931; Nelson, 1938; Moorrees, 1957; Stuart Hunter and Priest, 1960; Goose, 1963; Kieser, 1990:4-6; Buikstra and Ubelaker, 1994; Mayhall, 2000). Almost all these methods have been based on maximum mesiodistal diameter (MD-front to back of the tooth) and maximum buccolingual diameter (BL-from the cheek/lip side to the tongue side) of each tooth (Scott, 1991:791). Similar measurements of the cervical region (where the enamel meets the root), an area suggested to be less affected by tooth wear, have also been proposed (Goose, 1963:127; Hillson et al., 2005; Stojanowski, 2007). Other studies are reported for crown heights and root lengths (Goose, 1963). In dental metrical analysis, as with craniometrical analysis, both manual measurement methods and geometric morphometric techniques are used (El-Zanaty et al., 2010; Ashar et al., 2012).

(ii) Factors Influencing Tooth Size Dimension

The size of teeth in modern humans is the smallest of any hominine throughout their evolutionary history, but there is a wide range in tooth dimensions between and within different populations (Garn et al., 1968; Brace and Ryan, 1980; Brace et al., 1987,1991; Scott and Turner, 1997; Hillson and Fitzgerald, 2003; Fitzgerald and Hillson, 2008). Over the past decades attention has been given to factors controlling tooth size variation. Diversity in tooth size seems to have a strong "genetic" component, but "environmental" factors are also important (Townsend and Brown, 1978a-b, 1979; Townsend, 1980; Brook, 1984, 2009; Fearne and Brook, 1993; Dempsey and Townsend, 2001; Hillson, 2002:79; Townsend and Brook, 2008; Brook et al., 2009a; Townsend et al., 2009,2012). However, it is not easy to distinguish the relative

interactions and contributions of genetic and environmental factors. It is assumed that these factors may differ between individuals, population groups, the sexes, different teeth or part of the dentition, and even in part of a single tooth crown (Garn et al., 1966; Dempsey and Townsend, 2001; Hillson, 2002:79; Hillson and Fitzgerald, 2003; Brook et al., 2009b). Some odontometric studies suggest a single factor for the size of each premolar and molar, but that there are separate factors inherent for the mesiodistal and buccolingual dimensions of anterior teeth (Kolakowski and Bailit, 1981).

(a) Non-genetic or environmental factors

Non-genetic and environmental factors such as the prenatal environment and the mother's health during pregnancy (poor nutrition, smoking, disease, trauma, and infection), and early childhood illness influence tooth development and size (Bailit, 1975; Garn et al., 1979; Guagliardo, 1982; Scott and Turner, 1988; Scott, 1991:34; Heikkinen et al., 1994, 1997; Dempsey et al., 1999; Stojanowski et al., 2007; Brook, 2009). Factor such as low birth weight are also suggested to be associated with tooth size reduction (Bailit and Sung, 1968; Keene, 1971; Fearne and Brook, 1993). Diet and mechanical factors such as mastication and changes in food preparation techniques are suggested to have an effect on tooth size, and particularly the molars (Townsend and Brown, 1978a; Lukacs et al., 1983; Lukacs, 1985; Brace et al., 1991). It is suggested that with the use of pottery and the adoption of specific cooking techniques, the amount of necessary chewing was reduced, and this resulted in tooth-size reduction (Brace and Hinton, 1981; Lukacs et al., 1983; Brace et al., 1987,1991). This is a phenomenon that appeared in Europe, China, the Middle East, Japan and South Asia simultaneously (Brace et al., 1987). On the other hand, research shows that the amount of protein, lipid, and total calorie intake appear to increase tooth size (Stojanowski et al., 2007), and males show larger dental dimensions than females (Brook, 1984; Townsend and Alvesalo, 1985a-b).

(b) Genetic factors

A series of family studies of modern human populations based on odontometric comparisons among families, parents's children, twins, and siblings have confirmed that genetic and polygenic factors are indeed important contributors to variation in dental development and tooth size (Horowitz et al., 1958; Osborne et al., 1958; Garn et al., 1965; Potter et al., 1968; Townsend and Brown, 1978a-b, 1979; Scott, 1991:33-34;

Dempsey et al., 1999; Dempsey and Townsend, 2001; Townsend et al., 2009). Some studies maintain variations in dental size are attributable to single gene or multiple genes acting together and it seems that different teeth may have different heritability (Alvesalo and Tigerstedt, 1974; Potter et al., 1976; Potter and Nance, 1976). However, Brook (2009:3) noted that 'interactions, gradients and spatial field effects of multiple genes, epigenetic and environmental factors all influence the development of individual teeth, groups of teeth and the dentition as a whole.' The patterning of tooth size dimension among human populations is almost parallel to those obtained from genetic and craniometric data (Hanihara and Ishida, 2005; Herrera, et al., 2014). Integrating dental metrical data with genetic analysis to investigate biological affinities showed a significant association between mtDNA and odontometric data (Stojanowski et al., 2007). It is widely accepted that odontometric variation provides useful information on inheritance and it is an important and valuable tool for assessing biological relatedness and distance among individuals and groups; it can also provide additional information on the origin of human populations (Scott and Turner, 1988; Kieser, 1990:1; Scott, 1991:795; Dempsey and Townsend, 2001).

(iii) Tooth Size Variation and Past Population Studies

Numerous scholars have studied dental metrical variation among different modern and ancient human populations on a worldwide scale, within regions, between populations, and among specific ethnic groups in order to investigate biological distance and gene flow (Brace and Hinton, 1981; Lukacs, 1985; Harris and Bailit, 1988; Harris and Rathbun, 1991; Lukacs and Hemphill, 1993; Hanihara, 1993, 2010; Matsumura and Hudson, 2005; Stojanowski and Schillaci, 2006; Scherer, 2007; Stojanowski et al., 2007; Matsumura et al., 2009; Morita et al., 2012). In order to better understand the pattern of biological affinity, gene flow, and migration in different human groups, however, some researchers have incorporated and compared odontometric analysis with data on dental and cranial non-metric traits, as well as craniometric analysis (Smith et al., 1981; Hanihara, 1992; Matsumura et al., 2001, 2008, 2011; Matsumura and Dodo, 2009; Kaburagi et al., 2010). For example, Matsumura (2006:44-48) compared dental metrical and non–metric data of Southeast Asian populations in order to study biological affinities and relatedness. The data demonstrated that modern people in Southeast Asia share common features with Northeast Asian populations, suggesting that people in Southeast Asia were generally influenced by Northeast Asians. In another example

Hanihara and Ishida (2005) compared crown dimension of 72 major human population groups and seven geographic groups globally to evaluate the odontometric characteristics and degree of biological relationship among the populations from these major regions. They provide worldwide patterning of odontometric variation and found that Australians, Melanesians, Micronesians, Sub-Saharan Africans, and Native Americans had the largest teeth. However, East/Southeast Asians and Polynesians are intermediate in overall tooth size, and Philippine Negritos, Jomon/Ainu, and Western Eurasians have had the smallest teeth. Their data also indicate a similarity in dental size between East/Southeast Asians and sub-Saharan Africans. Based on their studies, they grouped populations as "microdontic", "mesodontic", or "megadontic". A further study by Morita and colleagues (2012) looked at tooth size variation alongside the strontium isotope ratios of people buried at two Jomon sites in Japan to investigate questions about inter-population genetic relationships and migration. They found that dental metrical variations were significantly associated with the distinction between immigrants and locals determined from the strontium isotope ratio data. This study is an interesting diversion from the traditional kind of studies.

(iv) Contribution of Dental Metrical Analysis to the Study of Ancient Iranian Population History

Morphological and size differences in human teeth have been studied less in Iran. However, neither living nor prehistoric series provide an adequate database for understanding dental evolution and variation in Iranian populations. Analyses of ancient Iranian dentitions are particularly sparsely represented in the literature. In early studies of skeletons from ancient Iranian sites (the early first-half of the twentieth century), however, teeth were not considered essential components of skeletal analysis, since most analysis were concentrated on craniofacial variation rather than dental variation (e.g., Rathbun, 1972). However, recently O'Neill and Hemphill (2011) compared dental metrical data collected from 139 individuals from the Bronze Age site of *Tepe Hissar* with data from 465 individuals from 12 archaeological sites in Central-Asia and the Indus-valley. The results showed consistent affinities between the inhabitants of *Tepe Hissar* and south Central-Asians. It seems that *Tepe Hissar* inhabitants experienced gene flow from Middle Bronze Age populations of southern Turkmenistan. There was also a similarity between the *Tepe Hissar* population and the inhabitants of Iron Age

Hasanlu IV in the west of Iran. However, these data are only contained in a conference abstract and full publication is needed.

3.1.3. Stature

Estimating individual height from long-bone lengths has a long history in human skeletal studies (White and Folkens, 2005:398). Long-bone lengths illustrate standing height due to the biometrical relationship between body segment lengths and total individual height; therefore, long bones have been used for stature estimation of archaeological skeletons (Mays, 2010:130).

(i) What Influences Final Attained Stature?

Human growth is a multifactorial process affected by multiple genetic, environmental (e.g. disease) and nutritional factors that all affect attained adult height (Steckel, 1995:1903; Attie, 2000; Zakrzewski, 2003; Palmert and Hirschhorn, 2003; Ortner, 2003:41; Bogin, 2013). It is thought that health and nutritional status play important role in an increase/decrease in height (Steckel, 1995:1910). Studies show a close relationship between growth suppression and dietary stress in childhood and final adult height, but with recovery and better nutrition "catch up growth" can occur (ibid, 1995:1911). A diet poor in iron, vitamins and animal protein/fat, poor health, exposure to infectious disease, and hard manual labour during childhood can cause stunting of growth (Sieber and Lippman, 1980:29; Rimoin et al., 1986; Steckel, 1995:1910; Rivera et al., 2003; Akachi and Canning, 2007). For example, children with vitamin D deficiency and rickets are more at risk of being short for their age in stature (Yeste and Carrascosa, 2003; Holick, 2005; Cooper et al., 2005), but the extent of short stature depends on the severity and duration of vitamin D deficiency (Thacher et al., 2002). On the other hand, it is assumed that individuals with an adequate well balanced diet tend to reach their genetic growth potential (Steckel, 1995:1911). However, some studies have found a lack of correlation between reduced stature and nutritional and health stress in archaeological populations (Ribot and Roberts, 1996; Humphrey, 2000). Variation in height is "genetically" controlled in any circumstances and even under widespread nutritional stress (Jepson et al., 1994; Palmert and Hirschhorn, 2003; Lettre, 2009, 2011).

(ii) Methods of Stature Estimation in Bioarchaeology

There are two methods used to estimate adult human stature in archaeological skeletons, anatomical and mathematical. The anatomical method (Fully, 1956; Lundy, 1985) involves summing the lengths of different parts of the skeleton from the foot through to the head to estimate total skeletal height directly, and provides more accurate estimates (Petersen, 2005; Raxter et al., 2006, 2007,2008; Vercellotti et al., 2009; Auerbach and Ruff, 2010). The measurement of stature in the grave (in an extended supine position) is another "version" of the anatomical method and was at the time regarded as the most accurate method for estimating the living stature; however, it is difficult to use this method for skeletons buried in positions other than supine (e.g. prone, flexed or sitting position) or displaced skeletons in *situ*. Both these methods require excellent skeletal preservation, so they are less applicable to many archaeological skeletal remains particularly those with a poor state of preservation (Peterson, 2005; Raxter et al., 2008; Vercellotti et al., 2009). However, in the cases of incomplete and limited number of skeletal elements especially in archaeological collections, it is possible to estimate stature from the mathematical regression formulae, using the length of one or few skeletal elements (Auerbach and Ruff, 2010). But, the regression formulae should be chosen carefully for archaeological human remains since the ancestry of individual/population under study may be unknown. On the other hand, 'ancestry alone may not be a good predictor of which stature equations to use' (Vercellotti et al., 2009:136), as factors for example environment and nutrition also can influence body proportion and stature of an individual from the same population and genetic background (Vercellotti et al., 2009; Riversa et al., 2003). However, people are using relative long bone length too and not putting measurements into regression equations, suggestig regression introduces error (e.g., Sjøvold, 1990; Raxter et al., 2008).

There are also different methods to determine stature from a variety of skeletal elements, e.g. foot bones (Cordeiro et al., 2009; Pablos et al., 2013), Cephalo facial anthropometry (Krishan, 2008), and phalangeal lengths (Habib and Kamal, 2010). However, stature in archaeological populations is best estimated by measuring maximum long bone lengths and using regression equations (Mohanty, 1998; Duyar and Pelin, 2003). The most commonly used regression equations are those of Trotter and Gleser (1952, 1958, 1977) and Trotter (1970). They developed formulae for estimating stature based on known age, sex, and stature American "white" and "black" males

(World War II casualties), and "white" and "black" females, all from the documented Robert J Terry skeletal collection, Smithsonian Institution, Washington DC, USA. They then revised their formulae using American male casualties (Korean War), also with known age, sex and stature. They further provided larger samples and included Mexican and mixed "Mongoloid" samples (Trotter and Gleser, 1952, 1958, 1977). Therefore, to use the Trotter and Gleser method, sex and ancestry of the skeletal material needs to be known (Mays, 2010:131). Bass (1995:27-31) claimed that the Trotter and Gleser (1952, 1958) methods are the most reliable (and certain bones are best, particularly the femur and tibia as they best reflect stature), and they reproduced a useful table for stature estimation in different populations from their data. Jantz and colleagues (1994, 1995) tested the accuracy of the Trotter method and noticed that the length of the tibia had been incorrectly measured (the length was not measured to the end of the medial malleolus). They also noted that in the Trotter formulae when the tibia was used, stature estimates were about 2-3cm greater than when measuring the tibia "properly". Therefore, they proposed 'that anyone using Trotter's WWII stature estimation formulae (Trotter and Gleser, 1952) should measure "maximum" tibial length from the most proximal part of the lateral half of the lateral condyle to the most distal projection of the bone, not including the malleolus.' (Jantz et al., 1994:528). However, 'when using the Korean War dead formulae (Trotter and Gleser, 1958), the investigator should probably measure "maximum" tibial length as Trotter described it including the malleolus.' (Jantz et al., 1994:528). Feldesman et al. (1990) stated that there is a strong relationship between femur length and stature in both sexes, along with ethnicity, and Feldesman and Fountain (1996) stated that in a person of unknown ancestry femur length is the most accurate bone to use overall.

3.2. Non-Metric Analysis of Skeletal and Dental Remains

Non-metric traits are macroscopic features of "phenotypic" expression (variation) in the skeleton, including the dentition, due to the effects of modifying genes and/or different environmental conditions during development, manifesting in varying degrees of expression (Saunders, 1989:95). It has been shown that this "phenotypic variation" reflects "genotypic variation" between individuals and groups of people (Movsesian, 2013; Herrera, et al., 2014). Many non-metric traits are assumed to be passed from parents to children, and therefore they can be an expression of the genes in a given population (Laughlin and Jorgensen, 1956; Berry and Berry, 1967; Tyrrell, 2000:289).

These traits can provide an alternative to genetic indicators when assessing general affinity patterns between human groups (Ricaut et al., 2010; Herrera et al., 2014). Non-metric traits show considerably different frequencies among human groups and are usually recorded on a nominal scale (present/absent) or on an ordinal/ranked scale (Saunders, 1989:95; Tyrrell, 2000:290; Saunders and Rainey, 2008:533). Such traits represent normal variation as opposed to pathological changes (abnormal variation) and are not only visible in skeletons and dentitions of humans and animals, but also in early hominines (Grüneberg, 1952; Wood and Abbott, 1983; Irish, 1997,1998). Non-metric traits have been widely used in forensic studies for identification purposes (Hefner et al., 2012), bioarchaeological studies of family relationships and in research on biological distance and genetic relationship (gene flow- Ossenberg, 1976,1977; Alt et al., 1997; Tyrrell, 2000:289; Stojanowski and Schillaci, 2006; Ricaut et al., 2010; Hanihara et al., 2012). However, some are now recognised to represent a manifestation of activity related stress in individuals, particularly the postcranial traits (Ossenberg, 1970; Pucciarelli, 1974; Larsen, 1997:303).

(i) Naming Non-Metric Traits and Methods of Recording

There are many different synonyms for these traits. The most commonly used adjectives to distinguish these traits include: discrete, non-metric, morphological, discontinuous, anomalies, quasi-continuous, threshold, minor, epigenetic, and secondary (Saunders, 1989:96; Saunders and Rainey, 2008:538). The term "non-metric variants" is an older expression and was used by Berry (1968), meaning that these traits are not measurable on an interval scale for other linear measures of skeletal elements, and this term has become common usage in bioarchaeology (Saunders, 1989:96; Buikstra and Ubelaker, 1994:85; Scott and Turner, 1997:25; Scott, 2008:265). The term "epigenetic" was used by Berry and Searle (1963) to emphasise that each trait is controlled by the additive effect of genes, which indicates in this case lack of environmental influence on trait development (Hauser and De Stefano, 1989:1). However, later on Falconer (1965) suggested that environmental factors may influence the development of non-metric traits which may cause fluctuations in heritability of the same traits among different individuals and populations (cited by Tyrrell, 2000:291). The name "quasi-continuous" was introduced by Grüneberg (1952). This describes the two processes involved in their determination: 1. the underlying continuous variable which is influenced by the action of a number of genes, and 2. discontinuity imposed by the existence of alternative

possible end results of development, which is the epigenetic consequence of interaction or competition between different developmental processes (Berry and Berry, 1967).

Unlike many measurements of the skeleton, non-metric traits can be recorded easily on fragmentary and incomplete bones, do not need particular equipment, and in practical terms scoring of traits as present or absent can be done quickly on very large numbers of skeletons (Berry and Berry, 1967). However, some skeletal and dental non-metric traits are not easily identifiable. On the other hand, it is not easy to record some traits on fragmentary/damaged teeth (e.g., groove patterns) or tooth with heavy attrition or pathology (e.g., heavy caries). Studies have shown that non-metric trait occurrence is largely free of sex and age bias, although intra-and inter-observer error must be considered (Berry and Berry, 1967; Berry, 1968:125-126; Ossenberg, 1976, 1977; Turner et al., 1991; Tyrrell, 2000:292; Jackes et al., 2001). Therefore, different frequencies of traits can be used for biological distance studies among ancient populations (Hanihara et al., 2003). Theoretical models of population biodistance analyses are relatively straightforward; populations that exchange mates share high/low frequencies of similar traits and are more biologically related than a population with different or fewer similar traits (Larsen, 1997:302; Stojanowski and Schillaci, 2006; Saunders and Rainey, 2008:538).

During the past several decades, a wide range of traits have been reported for the cranial and post-cranial skeleton and the dentition (Berry and Berry, 1967; Ossenberg, 1969, 1976; Finnegan, 1978; Saunders, 1989; Hauser and De Stefano, 1989; Turner et al., 1991; Scott and Turner, 1997), which have been widely and successfully utilized in bioarchaeological studies as phenetic markers to assess biological variation and genetic relationships among ancient individuals and between populations (Ricaut et al., 2010; Movesesian, 2013).

3.2.1. Cranial Non- Metric Traits

According to Ossenberg (1969, 1970) and Hauser and De Stefano (1989) most traits can be classified into four major classes: “hyperostotic” or abnormal proliferative ossification such as bony spurs or bridges, “hypostotic” or ossification failure leading to defects, ossicles (small bones) located within cranial sutures, and variation in foramina, canals, and grooves for blood vessels and nerves (Ossenberg, 1969, 1970; Dodo, 1974; Hauser and De Stefano, 1989; Saunders, 1989; Buikstra and Ubelaker, 1994:85; Hanihara and Ishida, 2001a). There are also some traits that can be placed into both

hyperostotic or hypostotic patterns of trait variation such as an accessory optic canal and hypoglossal canal bridging, and jugular canal bridging (Saunders, 1989:96).

(a) Hyperostotic traits

Hyperostotic traits involve abnormal bone formation or excess ossification in soft tissues structures (Figure 3.1) (e.g., cartilage or ligaments) (Ossenberg, 1969; Saunders, 1989:96). Hypoglossal canal bridging, jugular canal bridging, peterygoalar bridge, mylohyoid bridge, trochlear spur, and palatine bridging are some examples of hyperostotic traits (Saunders, 1989:96; Saunders and Rainey, 2008:539). It is suggested that, when considering differences by sex, age and side (Ossenberg, 1970), hyperostotic traits show a slight preference for male skulls and on the left side, and tend to follow an age-progressive pattern (Ossenberg, 1970; Dodo, 1974; Saunders, 1978).

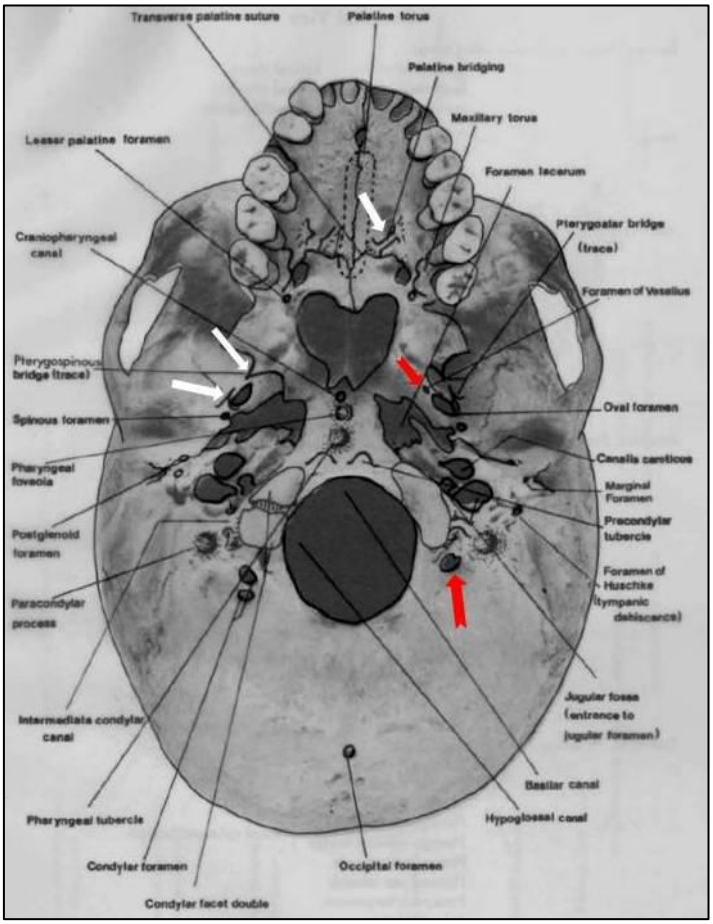


Fig 3.1. Examples of cranial non-metric traits: hyperostotic (white arrow), and foramina, canals, and grooves (red arrow) traits (from Hauser and De Stefano, 1989)

(b) Hypostotic traits

Hypostotic traits are those associated with incomplete ossification, regression or lack of bone formation (Figure 3.2), for example an aperture or hole in bone, infraorbital sutures, metopism, and os Japonicum (Ossenberg, 1969; Saunders, 1989:96; Saunders

and Rainey, 2008:536, 540). Despite minor differences in sex, age and side occurrence (Ossenberg, 1970), hypostotic traits occur slightly more frequently in female skulls and on the right side; it seems also that they follow an age-progressive pattern up to a certain age, after which they remain stable and this may be connected to small bone size and immature body features in females (ibid, 1970).

(c) Foramina, canals, and grooves for blood vessels and nerves

Morphological features such as foramina, canals, and grooves reflect variations in the presence, absence or pattern of division of blood vessels and nerves (Figure 3.1) (Ossenberg, 1969, 1970; Saunders, 1989:96; Hanihara and Ishida, 2001a–e). Each has its own characteristic pattern of occurrence by age, sex and side which, no doubt, could be interpreted if the underlying size variable in each individual could be identified (Ossenberg, 1970). For example, traits such as the supraorbital foramen or notch, frontal grooves, the post condylar canal, an accessory optic canal, parietal foramen, and foramen of vesalius are in this category (Ossenberg, 1969; Saunders, 1989:96; Saunders and Rainey, 2008:540).

(d) Supernumerary vault sutures

Supernumerary or wormian bones (ossicles) are located within cranial sutures (Figure 3.2) and act as additional centres of ossification (Ossenberg, 1969; Saunders, 1978; Saunders and Rainey, 2008:537). For example the os Inca, ossicle at lambda, coronal ossicle, parietal notch bone, ossicle at asterion, occipitomastoid ossicle, and epipteric bone are in this category (Ossenberg, 1969; Saunders, 1989:96).

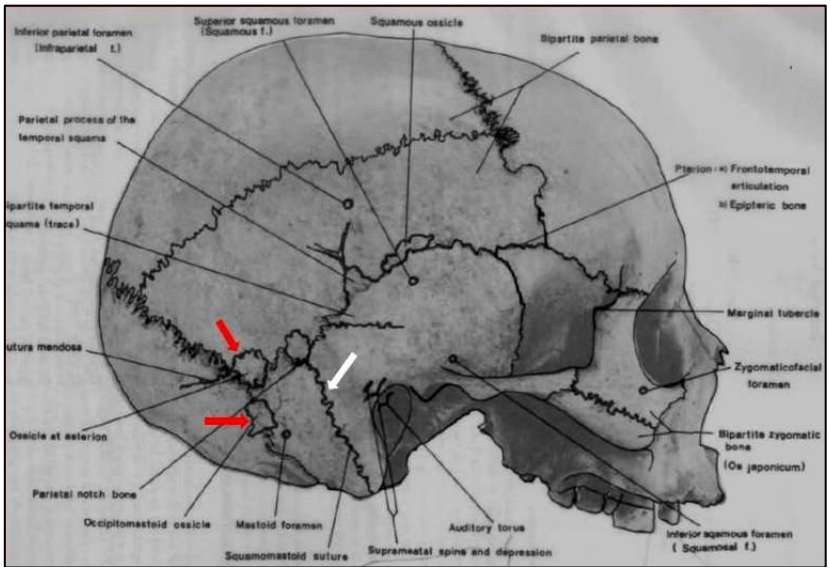


Fig 3.2. Examples cranial non-metric traits: hypostotic trait (white arrow), and supernumerary vault sutures (red arrow) (from Hauser and De Stefano, 1989)

(i) The History of Cranial Non-Metric Trait Studies

The early classification of non-metric traits in the human skeleton goes back to the 1670s when Dutch anatomist Kerkring first described some traits in the human skull. However, the familial occurrence of cranial traits was first recorded in 1893 by Shepherd and in 1895 by Symmers (Hauser and De Stefano, 1989:1; Tyrrell, 2000:290). During the 19th century the record of cranial traits grew rapidly as a result of access to human skeletons available for study from autopsies and in natural history collections (Saunders, 1989:95-96; Alt et al., 1998). In the early part of the 20th century researchers described the details of the cranial, facial and spinal traits (Lillie, 1917; Saunders and Rainey, 2008:542).

In 1922 Sullivan utilized the frequency of cranial and dental non-metric traits to determine the biological relationship between populations from Europe, Asia, Australia, Africa and America, and interpreted his results using racial categories. Sullivan argued for the use of non-metric traits in determining individuals and population relationship, when craniometric study cannot be used, for example cranial deformation (1922:203-7). He also indicated the need for a standardized method of scoring traits, as did the contemporary work of Hooton which was one of the earliest attempts to provide a scoring system for cranial traits (Hefner et al., 2012). Nevertheless, the early non-metric studies were consisted mostly of traditional descriptive and typological classifications and based on racial hierarchy and ancestry of individuals and populations (Saunders and Rainey, 2008:542), which generated the idea of using non-metric trait frequencies for population comparisons (Saunders, 1989:96).

In the 1950s, a significant shift in the nature of non-metric trait analysis occurred, when genetic control of trait inheritance was proposed (Prowse and Lovell, 1995). For example, Torgersen (1951) suggested that the metopic suture has a genetic basis in humans. In 1952, Grüneberg studied non-metric traits in mice and discussed the "quasi-continuous" nature of these traits and the potential value of non-metric skeletal variation in genetic studies (cited in Hauser and De Stefano, 1989:1). He found a lack of Mendelian inheritance, with most of them appearing as more than one expression, including different sizes, shapes, positions, and varying numbers (Hauser and De Stefano, 1989:1; Tyrrell, 2000:290), suggesting "multiple genes" controlling the occurrence of traits (Saunders, 1989:97). Unfortunately, there is limited research on the genetic basis for heritability in human cranial traits (Torgersen, 1951; El-Najjar and Dawson, 1977; Sjøvold, 1984; Carson, 2006a-b), because appropriate experiments are

impossible (Berry, 1975). However, it is suggested that Grüneberg's (1952) model 'provided a theoretical justification for the study of morphologically analogous traits in humans and led to familial studies of the inheritance of skeletal variants in humans and alloprimates, which identified a significant genetic component in the inheritance of some non-metric traits.' (Prowse and Lovell, 1995:105).

During the late 1960s there was a considerable increase in the number of methodological studies on cranial non-metric traits. Berry and Berry (1967) performed a systematic analysis of the frequency and distribution of 30 cranial non-metric traits in 585 adult crania from eight different regions in the world, north and south America, Burma, Nigeria, north India, Palestine (Lachish, modern), and Egypt, looking at biological distance between these populations. They found a lack of sex, age, side, and inter-trait correlation among samples and described the importance of non-metric traits studies of humans and its superiority to craniometric studies, but did not examine the heritability of these traits. They advocated cranial trait frequencies for determining biological distance among ancient populations (Berry and Berry, 1967). Twenty years later, this paper was modified and completed by Hauser and De Stefano (1989) (see below). Another important study at that time was Ossenberg's (1969, 1970) analysis of cranial non-metric traits in 3200 complete skulls from several North American populations: arctic maritime, middle to late Woodland from the northern Mississippi valley, and nineteenth century Dakota Sioux. She also found that age, sex, and side differences were small. Based on bone formation and soft tissue relationships, Ossenberg developed the classification system for cranial non-metric traits described above (section 3.2.1).

During the 1970s even more attention was paid to the importance of cranial non-metric trait analysis in biodistance studies (Corruccini, 1974; Spence, 1974a-b; Cheverud et al, 1979; Carpenter, 1976; Cosseddu et al., 1979; Perizonius, 1979; Ossenberg, 1976, 1977). For example, Corruccini (1974) recorded 72 traits for 321 human skulls from the Terry Collection. He identified significant sex and age differences and association between traits, in contrast to Berry and Berry and Ossenberg. In this period there was a polarized debate over the accuracy and ability of these traits for population comparisons, the genetic nature of these traits, the effect of environmental factors (e.g., cranial deformation), sex and age association, asymmetry, inter-trait correlations, and recording accuracy on trait frequency (Ossenberg, 1969, 1970; Corruccini, 1974; Carpenter, 1976; Cheverud et al, 1979; Trinkaus, 1978;

Perizonius, 1979). Some researchers argued that cranial measurements were more accurate and reliable for population relationship studies (Rightmire, 1972), while others believed non-metric traits were more reliable for biodistance studies (Ossenberg, 1977; Cheverud et al, 1979). On the other hand, other studies suggested that both cranial measurements and non-metric traits shared similar patterns of development and underlying genetics and could be used together for interpretation of morphological differences among populations (Corruccini, 1974; Trinkaus, 1978; Cheverud et al, 1979; Prowse and Lovell, 1995).

In the late 1980s, based on Berry and Berry (1967), Hauser and De Stefano (1989) conducted a more comprehensive study and produced a systematic reference atlas book that includes description, embryology and development, variation, frequency, and methods of scoring of 84 cranial non-metric traits with a number of high quality drawings. Some of these traits were estimated to have high heritability, while the majority of them were estimated to have rather low or zero heritability. Although the possibility of investigating the inheritance of these traits in humans is limited, since there are few with known family relationships (Hauser and De Stefano, 1989:2), recent biological distance studies have used cranial non-metric traits to assess biological affinities of various populations. For example, Hanihara and Ishida (2001a-d) conducted a comparative systematic analysis of cranial traits among worldwide modern human populations from different genetic backgrounds. They compared the frequency of supernumerary ossicle sutures, hypostatic, hyperostotic, and vessel and nerve related variations among 10,000 non-deformed skulls. They identified heritability as the underlying cause for the observed regional variation in the case of cranial "hypostatic", "hyperostotic", and "foraminal/canalised" traits (ibid, 2001b-d). They hypothesised that sutural variants are not under direct genetic control, however, ontogenetic stresses such as cranial deformation could be the basic cause of development of ossicles, but this hypothesis may not be applicable for the other populations in the world (Hanihara and Ishida, 2001a). They suggested that 'the diversity of modern human discrete cranial traits may at least in part be attributed to differential retention or intensification from an ancestral pattern caused possibly by genetic, ecological, adaptational, and demographic background.' (ibid, 2001d:281). Later, Hanihara and colleagues (2003) conducted a comprehensive study of cranial traits on 70 major modern human populations from around the world with the purpose of examining if cranial traits provided biological distances similar to those found in genetic and other morphological analyses. They

argued that their data were compatible with results of other craniometric analyses of global populations and genetic data (Relethford and Harpending, 1994; Hanihara et al., 2003), suggesting that cranial traits provided additional data for population affinity studies (Hanihara et al., 2003).

In summary, approximately 200 traits have been reported for the human skull (Ossenberg, 1976). Some of these traits are believed to have a genetic background (Laughlin and Jorgensen, 1956; Berry and Berry, 1967; Sjøvold, 1984; El-Najjar and Dawson, 1977), while some are likely to be environmental, pathogenic or mechanically induced (Saunders, 1989:105; Brothwell and Zakrzewski, 2004; Bergman, 1993; Ossenberg, 1969, 1970; Larsen, 1997:303), or perhaps are partially heritable (Carson, 2006a-b; Saunders, 1989:105). For example, highest nuchal line or auditory exostoses is believed to be markers of activity related stress (Capasso et al., 1999; Tyrrell, 2000) as clinical studies showed an association between auditory exostoses and habitual diving in cold water (Kennedy, 1986). Nevertheless, the nature of many cranial non-metric traits is ambiguous and it is unknown whether genetic or environmental, or unknown factors, are responsible.

Thus heritability estimates for a trait in a population may not be applicable for other populations from different environmental/geographical areas or different time period. 'A heritability estimate is always specific to that sample. Change the environment and the same sample of individuals with exactly the same genotypes will have a different heritability estimate. Because of this, heritability estimates cannot be directly compared from samples not having either identical or environmental composition.' (Vitzthum, 2003:545). Therefore, as already discussed above, the presence of a biological relationship between two populations based on non-metric trait is a "phenotypic" observation (Saunders, 1989:104) which reflects genotypic observation between groups of people (Ricaut et al., 2010). For example, an increase in the frequency of "non-random" traits among skeletons in a cemetery may indicate family clusters and relatedness which can be due to genetic or environmental factors (Saunders, 1989:106; Larsen, 1997:303).

(ii) Cranial Non-Metric Trait Variation and Past Population Studies

The earliest population studies were conducted by Laughlin and Jorgensen (1956). They examined Greenland Eskimos, searching for evidence of regional differentiation and direction of movements of Eskimos isolated around the coast of Greenland. They

indicated that cranial non-metric traits were genetically determined and useful for family studies. Later, Brothwell (1959) studied 10 cranial non-metric traits and nine cranial measurements among 14 different populations from around the world, looking at biological distance between them. He suggested that cranial non-metric traits could be an alternative method to use for biological distance studies.

Cranial non-metric traits have been successfully used as phenetic markers in a large number of biological distance studies of archaeological populations around the world today (Dodo and Ishida, 1990; Pardoe et al., 1991; Powell and Neves, 1999; Sutter and Mertz, 2004; Stojanowski and Schillaci, 2006; Ricaut and Waelkens, 2008; Ricaut et al., 2010; Hanihara et al., 2012), particularly to compare biological affinities between past human groups on a regional or global scale (Prowse and Lovell, 1995; Ishida and Dodo, 1993, 1997; Rubini et al., 1997; Christensen, 1998; Godde, 2009; Nakashima et al., 2010; Nikita et al., 2012; Khudaverdyan, 2012). For example, Ossenberg (1977) studied biological distances among one Aleut and four Eskimo populations based on cranial traits and measurements, as well as linguistic geographic criteria. She argued that non-metric trait data showed stronger similarity to geographic location and linguistic tradition than the metrical data. She also found a significant correlation between traits and measurements for both sexes.

Prowse and Lovell (1995) adopted biological distance measures to investigate the relationships during the development of social complexity in ancient Egypt, and also to evaluate if cranial and dental non-metric trait analyses lead to the same results. They examined 45 cranial non-metric traits among 135 skeletons from three cemeteries at Naqada, Egypt (3600-3000 B.C.) as well as from neighbouring regions including Upper Egypt (3800-300 B.C.) and Lower Nubia (3000-2750 B.C.). They found no significant correlation between traits and age and sex among the samples, but they found a similarity between the cranial and dental non-metric traits which indicated that the individuals buried in the elite cemetery at Naqada were significantly different from individuals buried in the other two cemeteries. However, the individuals in these two cemeteries showed a close relationship. Individuals in the elite cemetery were more similar to populations from northern Nubia than to populations from Upper Egypt.

Ricaut and Waelkens (2008) utilised cranial non-metric traits to investigate the population movements and biological history of a Byzantine population (11th–13th century A.D.) from Sagalassos, south-west Turkey. They examined the frequency distribution of 17 traits among the Sagalassos population and 27 modern, historic and

prehistoric Eurasian and African populations. The data showed biological affinity between Sagalassos and eastern Mediterranean populations as well as with sub-Saharan and northern and central European populations, suggesting migration to southwest Anatolia from these regions.

Unfortunately, there have been few bioarchaeological studies on cranial non-metric traits for ancient Iran. Rathbun (1979) examined 31cranial traits, and 17 post-cranial traits, along with nine cranial measurements to investigate biological affinities among 833 "Metal Age" skeletons from Southwest Asia, Iran and Iraq. The results suggested 'widespread female homogeneity through time and contrasts with the male pattern of localized heterogeneity.' (ibid:473- see section 3.1.1 (iv)). He noticed that the data corresponded to those from the craniometrical analysis. However, these data are limited (conference abstract). The present cranial non-metric study thus will be a landmark for future research in Iran.

3.2.2. Post-Cranial Non-Metric Traits

Some researchers have suggested that post-cranial non-metric traits are also useful in biological distance studies among ancient populations (Finnegan, 1978; Finnegan and Cooprider, 1978; Finnegan and McGuire, 1979). The system of classification for cranial non-metric traits (Ossenberg, 1969) was later adopted by Saunders (1978) for post-cranial non-metric traits. Post-cranial traits usually appear in "hyperostotic" or "hypostotic" forms (see section 3.2.1) (Saunders, 1978, 1989; Buikstra and Ubelaker, 2004:85). Supratrochlear spurs of the humerus, atlas bridging (posterior, lateral), double cervical transverse foramen, third trochanter of the femur, and peroneal trochlea of the calcaneus are some example of post-cranial "hyperostotic" traits. The humeral septal-aperture and sternal foramen are examples of "hypostotic" traits (Figure 3.3) (Saunders, 1989:96).

Fig 3.3. Left:example of hyperostotic trait (supratrochlear spur of the humerus) and Right:an example of hypostatic trait (humeral septal-aperture), both from Tepe Hissar

(i) The History of Post-Cranial Non-Metric Trait Studies

The earliest report for postcranial non-metric traits goes back to the early 1820s (Trotter, 1934). Later studies include Trotter's (1934) paper on the occurrence of the humeral septal-aperture among skeletons with known ancestry, sex and age. She explained it as a "racial" variation, but Glanville (1967) indicated that the cause could be both genetic and environmental (e.g., mechanical movement of elbow).

Finnegan (1974) studied the frequency of 30 post-cranial traits with a number of cranial traits among Coastal Eskimo, Yukon Eskimo and Aleut skeletons to assess biological distances between these populations. The results showed a considerable "overlap" between the frequency of post-cranial and cranial non-metric traits. Therefore, he suggested that post-cranial traits may be as useful as cranial traits in population studies (Finnegan, 1978). Later, Finnegan (1978) studied 30 post-cranial traits in "black" and "white" American skeletons from the Terry Collection and found no significant side differences in frequency. Sex differences were statistically significant for some of the traits within a particular "racial" group, with some age dependency (ibid). Saunders (1978) conducted systematic research on the frequency of 50 post-cranial traits among 1400 individuals from three population groups: Arikara Native Americans, Native Americans from sites Libben- Ohio, and Eskimo-Aleut populations. She divided traits into "hyperostotic" and "hypostotic" forms and indicated that hyperostotic traits were more common in males, on the right side of the body, and showed an increase in frequency with age. She suggested that some post-cranial traits are as useful as cranial traits for population biodistance studies (Donlon, 2000).

Saunders and Rainey (2008:538) indicate that the "phenotypic" expression of post-cranial traits can be a result of both genotypic and environmental influences. Nevertheless, as with cranial traits, the development basis and heritability of post-cranial traits are not well understood and in most cases post-cranial traits are more susceptible to remodelling or are caused by activity induced stress rather than genetic factors (Capasso et al., 1999; Donlon, 2000; Tyrrell, 2000:294). For example, the humeral septal aperture has been attributed to robusticity/joint hypermobility; squatting facets attributed to a squatting posture/kneeling; the trochanteric exostosis to kayaking with the legs extended (among Aleut males); or the Poirier's facet as a marker of squatting (Larsen, 1997:303; Capasso et al., 1999; Boulle, 2001; Mays, 2008; Villotte and Knüsel, 2009).

Larsen, (1997:303) indicates that the consistency of findings that the underlying cause of come non-metric traits is biomechanical adaptation or activity fits with other lines of evidence and can provide valuable information about population structure and relatedness. Sokal and Sneath (1963) state '….there are no distinct large classes of genes affecting one group of attributes exclusively. Thus there is no theoretic reason that infracranial nonmetric traits should not do as well as other osteologic data sets in addressing questions of population relationships.' (cited in Donlon, 2000:351). However, consistency in the presence of some similar traits among individuals, in addition to the evidence of trait frequency from crania and dentitions could be an indicator of morphological similarity between people.

(ii) Post-Cranial Non-Metric Trait Variation and Past Population Studies

Several studies utilised post-cranial non-metric trait frequency alone or in combination with cranial and dental traits to investigate human activity or biological relationships in past populations. For example, Boulle (2001) studied 543 historical French individuals (1^{st}-18^{th} A.D.) for which no specific activity was known, and a number of skeletons from the Hamann-Todd collection to examine the frequency of squatting facets. He attributed this trait to squatting and suggested that this posture was a regular behaviour in ancient French populations until the end of the Middle Ages, but after this period the frequency of this trait decreased, suggesting change in lifestyle. Baykara and colleagues (2010) considered the frequency of squatting facet among adult individuals from medieval Dilkaya and Van-Kalesi in Eastern Turkey. The authors reported a high frequency of lateral and medial squatting facet for both populations. They suggested that the high frequency of squatting facets may be an indicator of daily activity.

Post-cranial non-metric traits have been used in biodistance studies, for example, Donlon (2000) studied 40 post-cranial traits among 467 modern and ancient populations originating from five major geographic regions to assess population relationships. He showed the value of post-cranial traits in biodistance studies, proposing that they may be best used in studies between groups within a region, rather than in unrelated groups from different geographical area.

Ricaut and colleagues (2010) studied a combination of 63 cranial, post-cranial, and dental non-metric traits to compare the pattern of relationships among individuals from the Egyin Gol necropolis, Mongolia (3^{rd}-2^{nd} century B.C.), comparing with genetic

data from this site to evaluate general effectiveness of non-metric traits for detecting familial relationships in the absence of genetic data. Their results confirmed the results from mtDNA, Y-chromosome, and autosomal STRs. No study has been carried out on post-cranial non-metric traits for Iranian populations, so the current post-cranial non-metric study will be a land mark for future research in Iran.

3.2.3. Dental Non-Metric Traits

Teeth are the most dense and durable structures in human body and the most frequently found part of the skeleton at archaeological sites (Hillson, 1996). They are strong, genetically conservative in evolution, with a low susceptibility to post depositional degradation, and vary morphologically among populations (Scott and Turner, 1997:12). Teeth exhibit extensive variation in form within and between populations that can be easily observed in both living and archaeological humans (Scott, 1977). The development of deciduous and permanent teeth takes place *in utero*, suggesting that they are less influenced by environmental factors (Tyrrell, 2000:296). Dental traits are characterized by high heritability in familial studies of living populations (Scott and Turner, 1997:12; Larsen, 1997:306). 'Dental morphological traits do not vary without reason across the landscape…' (Scott and Turner, 1997:12), however, they are part of a person's biological heritage that they carry with them when they migrate, much like their blood group, fingerprint patterns, and other biological traits (ibid, 1997:12).

The term dental non-metric trait is used for describing morphological variations of the crowns and roots, such as supernumerary cusps and roots, furrow patterns, accessory ridges, grooves, or different curvatures and angles (Scott, 2008:265). These traits are not only visible in living humans but are also seen in fossil hominins (Wood and Abbott, 1983; Irish, 1997, 1998). They have been used to assess "phylogenetic affinities" between fossil hominins and modern humans (Stringer et al., 1997; Irish, 1998; Tyrrell and Chamberlain, 1998; Bailey and Turner, 1999; Bailey, 2000, 2002; Coppa et al., 2001; Irish and Guatelli-Steinberg, 2003). Dental traits provide valuable data for differentiating human groups, and assessing evolutionary adaptability, isolation, inbreeding, and gene drift both in living and past human populations (Moorrees, 1957; Scott et al., 1983; Lukacs, 1984; Larsen and Kelley, 1991; Irish, 1997; Alt et al., 1997; Mayhall, 2000; Jacobi, 2000; Jackes et al., 2001; Coppa et al., 2007; Delgado- Burbano, 2007; Hanihara, 2008). They can also illustrate the particular effects of genes and the

environment on dental development (Scott and Turner, 1988). It is assumed that when human groups are isolated from one another for a period of time, their crown and root morphological features change in varying degrees, depending on the population size and the extent and duration of isolation. On the other hand, when different populations come into contact and interbreed, the resulting populations possess similar dental morphological traits and frequencies (Scott and Turner, 1997:12).

(i) The History of Dental Non-Metric Trait Studies

Dental non-metric traits were first observed by ancient Greeks and early European anatomists. However, systematic investigation into these variations began in the first half of the 19th century, where research dealt with one or a number of traits (Alt et al., 1998:18). From the 1830s to the 1940s workers such as Carabelli, Hrdlička, Gregory, Campbell and Shaw described traits such as Carabelli's cusp, "shovel shaped" incisors, tuberculum dentale of the upper incisors, upper and lower molar cusp number, lower molar with Y-groove pattern, and upper premolar and molar root number in a range of populations (Scott, 1997:335, 336; Scott and Turner, 1997:6, 7; Hillson, 2002:86). As cranial traits (see section 3.2.1), these were interpreted in terms of a racial hierarchy, but their work showed the importance of dental morphological study and provided some basic data and methodological descriptions for later comparisons (Scott, 1997:336).

There was a major advance in 1940-1960s, when attention was paid to understand the heritability of human dental variation (Scott, 1997:337; Mayhall, 2000:116). At this time, it became apparent that the development of accurate standards of recording was necessary, and this realisation led to the creation of plaster casts of traits to help standardize observations of dental non-metric traits in humans (Hanihara 1961; Dahlberg, 1963; Turnet et al., 1991; Scott and Turner, 1997:8). This was an important step to start using crown and root trait frequencies to measure population origins and biological relationships (Scott, 2008:266). Dahlberg's classification became the main source for the ASU scoring system presented below.

The investigation of dental non-metric traits has demonstrated that specific traits are associated with each major ancestral group (Hanihara, 1967; Berry, 1976). For example, shovel shaped maxillary incisors have been seen more commonly in populations of "Asian" origin (Mayhall, 2000), "Mongols" (Hanihara, 1967), "Eskimos", "American Indians" (Mizoguchi, 1985), and "Aleutian Islanders" (Moorrees, 1957), with lower frequencies in other population groups (Mayhall, 2000).

Hanihara (1967) also noticed some dental traits appeared to be characteristic of "racial" differences and were shared by all ancestral groups such as "Mongoloids", "Caucasians" and "Negroids", while other traits showed some degree of group difference which is significant in population and evolutionary studies. In this respect he proposed the term "Mongoloid dental complex" and "Caucasoid dental complex" for complexes seen at high frequencies in "Mongoloid" and "Caucasians" populations, respectively, and seldom or never seen in the other groups. Such general classifications provide useful guides for identifying individual ethnic affiliation in forensic contexts (Scott, 2008:287).

During the 1970-80s, however, more attention was paid to understanding the genetic nature of dental non-metric traits, and whether such traits were suitable for population comparison studies (Biggerstaff, 1973; Scott, 1974, 1977; Berry, 1976; Mayhall, 2000:124-126). Studies moved from the belief of a simple type of inheritance (Portin and Alvesalo, 1974) to a polymorphic type of inheritance (Goose and Lee, 1971; Lee and Goose, 1972; Scott, 1974; Berry, 1976; Scott and Turner, 1988:100). Some studies found no sexual dimorphism among samples (Turner and Hanihara, 1977; Scott, 1977, 1980; Mizoguchi, 1985; Harris, 2007), while others observed significant sex differences. Asymmetry of dental traits on antimeres was reported (Biggerstaff, 1973; Mayhall, 2000:125), as were noticeable side differences in expression of some traits (Mayhall, 2000:125), but many studies found no side preference (Scott, 2008:284-5). Nevertheless, it is suggested that each individual has only a single genotype to direct dental development, so the examination of one side of the jaw (either left or right) will increase the sample size and provide a realistic result (Mayhall, 2000:125; Irish, 2006; Scott, 2008:285). Factors such as selection (Dahlberg, 1963, Scott and Turner, 1988), mutation (Morris et al., 1978), environmental components (e.g., prenatal environment-Grüneberg, 1952; Searle, 1954a,b; Mayhall and Mayhall, 1971; Scott and Turner, 1988,1997:3; Brothwell and Zakrzewski, 2004), diet, disease and many other unknown factors during pregnancy (Saunders, 1989:97), as well as latitude and other geographic phenomena (Brues, 1977:137; Scott, 1980), may affect the development of the dentition and the traits.

The ASU system

More than 100 different dental traits have been identified in human dentition, but only 30 to 40 of these are well defined and standardised and currently are used in biological distance analysis (Scott and Turner, 1997:25). Turner and and his students,

following Dahlberg's classification and method, developed a new system at the Dental Anthropology Laboratory of Arizona State University for recording traits on permanent teeth in a standard way (Turner et al., 1991). It describes 38 morphological traits of the tooth crown and root with nine other features (ibid, 1991). Such traits are easily and reliably observed and recorded, are resistant to attrition, are consistently scored between observers, evolve very slowly, possess a high genetic component in expression, exhibit minimal or no sexual dimorphism or inter-trait correlations, and provide the maximum information with a minimum of observation time and cost (Turner et al., 1991; Larsen, 1997; Scott and Turner, 1997). It is believed that the ASU system traits provide powerful evidence for determining biological affinities among population (Turner et al., 1991:13). The ASU system is based on well-established criteria, a definition for each trait, and comprises a set of ranked-scale reference casts for scoring traits of the crowns and roots of the permanent dentition (Irish, 1997; Irish and Guatelli-Steinberg, 2003); they also show the variety of expressions (Dahlberg, 1963; Hanihara, 1967; Turner, 1985; Irish, 1997, 1998; Scott and Turner, 1997; Lukacs et al., 1998; Jacobi, 2000:70). The ASU casts have been distributed throughout the world and are the most commonly used in the study of dental traits in past and present populations (Alt and Vach, 1995; Irish, 1998, 2005, 2006; Jackes et al., 2001; Ullinger et al., 2005; Scott, 2008:272, Hemphill, 2011). The traits used in this system have been selected and incorporated into a standard data collection protocol and recommended as suitable standard traits for archaeological biodistance studies (Buikstra and Ubelaker, 1994).

(ii) Dental Non-Metric Trait Variation and Past Population Studies

To date, dental traits have been widely used by many researchers to describe and differentiate dentitions and biological relatedness between and within human populations from different regions around the world (e.g., Berry, 1978; Scott, 1980; Harris and Bailit, 1980; Turner, 1985,1987,1990; Haeussler et al., 1989; Turner and Markowitz, 1990; Irish, 1994,1997,1998,2005,2006; Guatelli-Steinberg et al., 2001; Irish and Guatelli-Steinberg, 2003; Ullinger et al., 2005; Edgar and Lease, 2007; Schillaci et al., 2009). The reconstruction of familial relationships in archaeological skeletal remains is a major challenge in bioarchaeological studies (Alt and Vach, 1995). Dental non-metric traits are usually used in biodistance studies of archaeological populations regionally and continentally, as well as in individual identification and

familial relationship (kinship) studies within a cemetery (ibid, 1995; Stojanowski and Schillaci, 2006).

Irish (1998) used the ASU method and performed comprehensive comparative analyses of dental non-metric traits from Plio-Pleistocene hominins to modern humans worldwide. He found that Sub-Saharan Africans showed significant differences in 11dental traits when compared to other populations in the world, but some of these traits represented ancestral dental characters and were prevalent in the dentitions of earlier hominids as well; some were also similar to early and modern non-human primates (Irish, 1997).

On an individual site basis, Lukacs (1988) used 17 dental non-metric traits from 90 individuals from Neolithic Mehrgarh in Pakistan, to investigate biological affinities between Neolithic and Chalcolithic inhabitants from Mehrgarh, and to compare people from Mehrgarh with the population from the Indus-valley Civilisation. The dental morphological data showed a close biological relationship between people from Neolithic Mehrgarh and later Chalcolithic people from Inamgaon in India and Timargarha in Pakistan, suggesting Mehrgarh's people may have been ancestors of the Chalcolithic people from western and central India.

In an early medieval kinship analysis, Alt and Vach (1995) examined the frequency of seven dental non-metric traits in 14 individuals from 19 graves containing repoussé sheet brooches from the burial ground at Kirchheim/Ries in Germany (6^{th} and 8^{th} A.D.). Of seven traits, four were frequent among these individuals but were rather rare in the overall population of the cemetery, and another three traits were present in all individuals and showed a frequency of more than 10%. The authors suggested that the spatial distribution of the individuals and the presence of the same dental traits support the hypothesis that these individuals were from the same family.

There has been little published on dental non-metric studies for ancient populations from Iran, as for cranial and post-cranial traits. Hemphill (2011) examined 17 dental traits in 23 prehistoric and living populations from South, West and Central-Asia, to investigate gene flow between these regions during the late third millennium B.C. Prehistoric samples were from Iran (Hasanlu IV, Hissar III), Central-Asia, and the Indus-valley. Living populations were from southeast India, west central India and Bengal. The results showed close affinities between Hissar III and Hasanlu IV in north-west Iran, and dentitions from Hissar III exhibited few or no affinities with Central-

Asian samples as well as the Indus-valley, for both prehistoric and modern populations. However, these data are limited (conference abstract).

3.3. Summary

The study of ancient population history and mobility is important in archaeological research. One of the key aims of the study of past populations is the assessment of temporal changes in biological structure over time and the possible cause of these changes. It is important to understand if biological change is due to population replacement, or introduced variations from elsewhere, or if it is just due to intrinsic developments (e.g., dietary change, adaptive shifts, microevolution, environmental influence- Larsen, 1997:310). Despite great progress in genetic and biochemical techniques for exploring human variability, morphological analyses of archaeological human skeletons, or a single skeleton in forensic anthropology are still the most frequently used methods for studying variability between individuals and populations (Donlon, 2000:351; Ricaut et al., 2010). Osteological analysis can therefore help the recognition of past population structure and history in the archaeological record (Mays, 2000b:285). Because skeletal and dental measurements and non-metric traits are thought to reflect genetic relatedness within or between populations (see above), for this reason they play an increasingly important role in assessing biological affinities among individuals and populations, for whom data on true genetic distances are usually unavailable for archaeological sites (Buikstra et al., 1990). Nevertheless, the reason for biological variability within archaeological skeletons is an unknown complex phenomenon. It is noted that skeletal remains recovered from cemeteries may not be contemporaneous, or ideally represent the original living biological population; they usually represent 'an accumulation of deceased individuals over time (sometimes several thousand years). Not all individuals in the sample are alive at the same time [, and]; therefore, some had zero probabilities of mating…. archaeological sites are often multicomponent in nature, and the derived sample may inter-mix distinct biological populations.' (Key and Jantz, 1990:53; see also Wood et al., 1992). These populations are not easily differentiated in an archaeological context. In addition, almost any human society contains different individuals from other societies and they may be incorporated into the (dead) sample and change patterns of variability (Key and Jantz, 1990:53). Therefore, it is proposed that studying within sample variability helps to address these

challenges and provides more accurate idata regarding biological distance among archaeological individuals and populations (ibid, 1990; Key, 1994).

The following chapter outlines the skeletal and dental indicators of stress, metabolic and dental diseases, and trauma/interpersonal violence.

Chapter 4 : BACKGROUND 2: ABNORMAL VARIATION-THE PALEOPATHOLOGY OF DIETARY INDUCED BIOLOGICAL STRESS AND TRAUMA

This chapter discusses skeletal and dental indicators of stress, and provides a detailed description of metabolic and dental diseases both based on clinical and paleopathological data. This chapter also presents a description of the study of trauma and interpersonal violence.

4.1. Stress and Disease

The concept of stress has been defined as a repetitive physiological reaction of individuals and populations to a disruptive variable or combination of variables and insults, and has much in common with the concept of adaptation (Buikstra and Cook, 1980; Goodman et al., 1988; Bush and Zvelebil, 1991). Stress is used in a variety of contexts in anthropological research, e.g., nutritional, environmental, mechanical or functional, psychological, and physiological (Larsen, 1987; Bush, 1991; Goodman, 1991). Factors such as a change in subsistence patterns, food shortage leading to famine, disease, a change in socio-cultural structures and lifestyle and economy, political instability, environmental degradation, migration, increase in population size, and climate change have significant impacts on a population exposed to these kinds of stressors (Goodman, 1991; House et al., 1994; Turner and Avison, 2003; Pearlin et al., 2005; Curtis et al., 2005; Temple, 2007). However, these factors might often interact with each other and in so doing can worsen other factors. For example, political instability or changes in social or cultur structures may lead to poverty because of food shortage and nutritional stress or vice versa. As an example, from bioarchaeology, Redfern and De Witte (2011) in their research on the Romano British populations of Dorset (1^{st}-5^{th} A.D) found that different social statuses and economies had a direct effect on an individual's health status. They concluded that people, who were of low social status, because of inadequate diet and nutritional stress, were more at risk of a metabolic disorder, infectious disease, and death. On the other hand, poor nutritional status in a population may affect work capability and resource production, resulting in significant cultural and social consequences (Goodman, 1993). Nevertheless, the conditions experienced by individuals and populations depend on different risk factors such as underlying genetics, age, sex, duration of stress, and the short or long term ability of the

population to buffer itself against these stressors; some individuals may also adapt to stress and some may not have the ability to do so (Goodman, 1991; Brickley, 2000:23; Roberts and Manchester, 2005:222).

Stress as a physiological disruption cannot be directly measured; however, different skeletal and dental changes may be used to infer stress (Goodman et al., 1988). If physiological stress becomes chronic then it may interrupt growth and leave its signature on bones and teeth, but it depends on the type of stressor involved (Buikstra and Cook, 1980; Goodman et al., 1988; Duray, 1996; Brickley and Ives, 2008). For example, health related stressors such as dietary deficiency can cause metabolic bone disease with different pathological lesions on both bones and teeth (Stuart-Macadam, 1989a; Dobney and Goodman, 1991; Aufderheide et al., 1998:405; Ortner et al., 2001; Brickley and Ives, 2008). The presence of the pathological lesions can also suggest other stressors affecting individuals, for example social/political instability, economic transition, population movement, disease, or environmental change, which may have led to nutritional stress in that society (Scott and Duncan, 1998:6; Pearlin et al., 2005). Nevertheless, the study of multiple indicators of skeletal and dental stress, in combination with other types of data, such as is found in archaeological, historical and epidemiological sources, has an important position in bioarchaeological research for assessing subsistence and dietary changes and general levels of health in prehistoric and historic communities (Goodman, 1993; Keenleyside, 1998). This approach has been used in much bioarchaeological research (e.g. Cohen and Armelagos, 1984; Lukacs, 1992; Lukacs and Pal, 1993; Pietrusewsky et al., 1997; Keenleyside, 1998; Lieverse et al., 2007; Eshed et al., 2010; Hubbe et al., 2012).

4.1.1. Skeletal Indicators

The skeleton of a living person can respond to stressful conditions in various ways, providing direct and indirect evidence (Larsen, 1997). The examination of stress indicators in skeletal remains is an important area of research in bioarchaeological studies (Lewis and Roberts, 1997). Bone forms by mineralisation of new bone by osteoblasts. Once formed, it is remodelled by osteoclasts (bone resorption) and osteoblasts (bone formation/replacement) working in combination. These bone cells are also responsible for the formation and remodelling of pathological lesions (Turner-Walker, 2008; Stevenson and Marsh, 2007:12). Skeletal lesions are expressed as abnormal bone formation, destruction, density, and size and shape which can involve

any part of the skeleton (Ortner, 2003:45). They can occur as the only sign of stress or in combination with other diseases such as infection, metabolic disease and cancer. However, it should be considered that burial practice and decay in the ground can also produce pseudo-pathological lesions (Wood et al., 1992; Keenleyside, 1998; Miller et al., 1996; Ortner, 2003:45).

Skeletal markers of stress have been used to understand the impact of socio-economic changes on nutritional status, health, and mortality of past populations (Cohen and Armelagos, 1984; Stuart-Macadam, 1989a). These include, metabolic disease such as scurvy (Maat, 2004), rickets and osteomalacia (Pinhasi et al., 2006; Brickley et al., 2007), and osteoporosis (Mays et al., 2006b). However, other non-specific indicators of stress have been used, such as DEH, reduced adult stature (Goodman et al., 1984), Porotic hyperostosis of the skull vault and cribra orbitalia (Brickley, 2000:28). Unfortunately, there are few published studies with reference to the impact of socio-cultural changes on skeletal or dental stress/health in ancient Chalcolithic and Bronze Age Iranian populations, including those from the Central Plateau. One rare example is that of Rathbun (1984) who compared skeletal pathology among Palaeolithic to the "Metal Age" (9000 B.C. to 300 A.D.) populations from Iran and Iraq. He indicated a decline in health represented by a slight decrease in stature, a marked increase in dental disease and attrition, and an increase in cribra orbitalia in the Neolithic compared to pre-agricultural groups, suggesting adjustment to a different economic base.

The paleopathological lesions which were recorded and expected to reflect stress in the population of *Tepe Hissar* are described in the following sections:

(i) Non-Specific

Porotic hyperostosis (PH) and cribra orbitalia (CO)

Porotic hyperostosis and cribra orbitalia are well known non-specific skeletal indicators of stress (Stuart-Macadam, 1992) but not the manifestation of a specific disease (Schultz, 2001; Ortner, 2003:102). They have been referred to as nutritional stress indicators (Goodman et al., 1988; Armelagos, 1990; Stuart-Macadam, 1992) and suggested to reflect metabolic insults that arise during the early years of childhood growth (Larsen, 1987). They are among the most frequent pathological lesions seen in ancient human skeletal collections (Walker et al., 2009), and considered to be one of several stress markers available for measuring their health and nutritional status (Stuart-Macadam, 1985, 1991).

Porotic hyperostosis and cribra orbitalia are characterized by an increase in the diploe (hyperostosis), and porosity and thinning of the compact bone of the outer table in the form of porotic lesions (Stuart-Macadam, 1987b,1991,1992; Aufderheide et al., 1998; Schultz, 2001). The lesions can involve both the orbital roof, known as cribra orbitalia and the skull vault, particularly seen on the frontal, parietal and occipital bones, and known as PH (Figure 4.1). The appearance is in the form of small holes of varying sizes (less than 1 mm to united holes) and distribution that penetrate the outer compact bone surface (see Resnick, 1995:2138; Schultz, 2001). In adults these lesions may show healing where the edges of the lesions have a smoother texture (Larsen, 1987; Aufderheide et al., 1998). Some researchers suggest the two pathologies share a common aetiology (Stuart-Macadam, 1989a,b; Schultz, 2001), but other paleopathological and clinical researchers suggest they often have different etiologies, since there is no clear link between the two (Aufderheide et al., 1998; Lewis, 2000:46; Walker et al., 2009). Both are frequently seen in skeletal samples from all over the world but much more often in non-adults than adults (Schultz, 2001; Ortner, 2003:102).

Although anemia has received much attention as a possible cause for PH and CO (Stuart-Macadam, 1987a-b, 1989a,1991), a number of other aetiologies are associated with the presence of these lesions (El-Najjar et al., 1975; Keenleyside and Panayotova, 2006). These include different genetic factors (Larsen, 1987), inadequate nutrition and vitamin deficiencies such as rickets and scurvy (Roberts and Manchester, 2005:230), inflammatory processes of the skull vault and scalp (Schultz , 2001), haemorrhagic processes affecting the external skull surface, tumours (Ortner, 2003; Schultz, 2001), anemia thalassaemia, sickle-cell anemia (Resnick, 1995:2110; Hershkovitz et al., 1997), infectious disease (Djuric et al., 2008), parasites such as malaria and hookworm (Roberts and Manchester, 2005:230; Sullivan, 2005), and perhaps lead poisoning which causes anemia (Stuart-Macadam, 1991; Warren et al., 1998; Crocetti et al., 2004:222). Wapler and colleagues (2004), based on histological analysis suggest that marrow hypertrophy, inflammation, pathological conditions (e.g., ophthalmic infections), or post-mortem erosion can also be linked to cribra orbitalia.

More recently Walker et al. (2009) argued that a vegetarian diet and lack of animal protein, poor sanitation, pregnancy and breastfeeding, vitamin B12 deficient maternal diets, and drought induced periods during warfare, famine and socio-economic collapse also provide plausible explanations for the high rates of porotic hyperostosis and cribra orbitalia in many prehistoric populations. These factors must be taken into

account when interpreting archaeological populations. Nevertheless, a careful and reliable reconstruction of the aetiology of these, in combination with other indicators of nutritional stress, has important implications for the interpretation of nutritional and health status in past human populations (Schultz, 2001; Walker et al., 2009).

porotic hyperostosis and cribra orbitalia have been more reported from human skeletal remains of the Neolithic period than the preceding Palaeolithic and Mesolithic (Meiklejohn et al., 1984; Smith, 1984). This has been suggested to be the result of iron-poor diets but also increased sedentism, population aggregation, and the introduction of cereal grains into the diet, the former resulting in greater exposure to pathogens (Angel, 1984:60; Stuart-Macadam 1989a:218, 1992). In the Neolithic period from Ganj Dareh (8500-7000 B.C.) in western Iran, none of the 49 individuals had CO, but an average of 23% of Bronze and Iron Age Iranian populations showed this lesion (Rathbun, 1984).

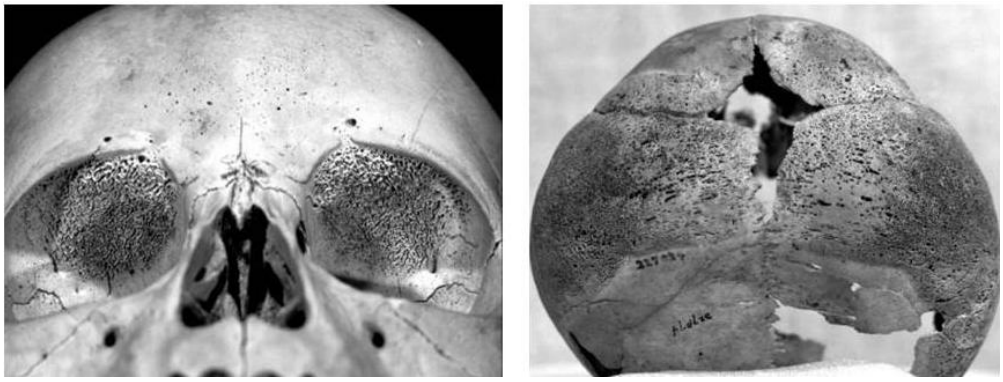


Fig 4.1. CO (left), PH (right) evident as indicated by pitting in the bone of the orbital cavities and skull vault (from Walker et al., 2009:Figures 1 and 2)

(ii) Metabolic Bone Disease

The metabolic bone diseases are disorders causing disruption of normal bone formation, remodelling or mineralization, or a combination of both (Roberts and Manchester, 2005:222; Holick, 2006). It is suggested that nutritional deprivation is the main factor in metabolic disease occurrence (Holick, 2006, 2008). Situations such as natural disasters, famine, warfare, socio-cultural changes and migration may contribute to the development of metabolic bone disease (Painter et al., 2005; Marcus and Menczel, 2007; Lewis, 2010). This is because individuals and populations may not have access to adequate food and necessary protein and vitamins in these circumstances. For example, Weisz and Albury (2013) studied 11 survivors (five females and six males) from the World War II famine i.e. those from the Holocaust who were exposed to starvation in their early life. These 11 individuals showed various levels of osteoporosis in addition to other metabolic diseases, suggesting that the risk of metabolic diseases,

particularly osteoporosis, in these individuals increased due to severe nutritional deprivation in their early childhood.

Deficiency in vitamin D (rickets, osteomalacia), vitamin C (scurvy) and the presence of osteopenia/osteoporosis may all be related to nutritional stress, lifestyle, and metabolic disorders (Hopper, 2000:31; Painter et al., 2005; Mays et al., 2006a-b), although most vitamin D is produced in the skin as a result of exposure to ultraviolet rays (Mawer and Davies, 2001; Chaplin and Jablonski, 2009). These conditions, however, can occur simultaneously with any or all of the other nutritional disorders in an individual, so careful attention is necessary to define the pathological features associated with each disorder (Ortner et al., 1999; Weisz and Albury, 2013).

The study of metabolic bone diseases is a particularly valuable source of information in understanding stress, diet, subsistence strategies, general living and environmental conditions, socio-economic status, cultural practices, and general health of individuals and populations, both past and present (Ortner et al., 1999; Painter et al., 2005; Brickley and Ives, 2008; Mays, 2008a:215). A good understanding of related pathological processes, with careful observation and accurate interpretations of relevant skeletal and dental lesions, along with having relatively complete and well preserved skeletal material makes it possible to diagnose metabolic bone diseases (Miller et al., 1996; Brickley, 2000:187; Ortner, 2003:393). It should be considered that diagenesis can affect preservation of bones so confusion may occur in diagnosis of metabolic bone related lesions as with other diseases (Ortner and Ericksen, 1997; Ortner, 2003; Brickley et al., 2007; Brickley and Ives, 2008). In the current research paleopathological lesions of the skeleton such as those associated with scurvy, vitamin D deficiency- residual rickets/osteomalacia, and osteopenia/osteoporosis are described in the following sections.

(a) Vitamin C Deficiency- Scurvy

Scurvy is the result of an inadequate amount, or the complete absence, of ascorbic acid (vitamin C) in the diet (WHO, 1999). Vitamin C is essential for many metabolic processes, but its most important role is in collagen formation, which is an important protein component for connective tissue and for the cement substance that connects the endothelial layers in blood vessels, skin, and cartilage (WHO, 1999; Hirschmann and Raugi, 1999). Any defect in collagen synthesis has many consequences, such as a tendency to haemorrhage following minor trauma to the fragile blood vessels, delayed

wound healing, petechiae, purpura especially affecting the legs, bleeding from the gums, and lack of bone formation in juveniles (Hirschmann and Raugi 1999; Pimentel, 2003; Maat, 2004). In some cases it may cause sudden death as a result of cerebral or myocardial haemorrhage (WHO, 1999).

Cause of scurvy

In humans the enzyme necessary to synthesize this vitamin is absent (Aufderheide et al., 1998; WHO, 1999), so exogenous vitamin C is needed. This vitamin is available in fresh fruits (particularly citrus), many vegetables, milk, meat and fish (WHO, 1999). Individuals with nutritional stress and a lack of fresh fruits and vegetables in their diet are more vulnerable to scurvy (Apostolakos and Halvorsen, 2014).

Different factors contribute to scurvy in humans such as multiple deficiencies, anemia, climatic extremes, a higher latitude, lifestyle, poverty and famine, or prolonged trips at sea, a high level of physical activity, and associated infectious diseases, creating circumstances that restrict access to vitamin C (WHO, 1999; Pimentel, 2003; Geber and Murphy, 2012). The method of food preparation and storage also has an effect on vitamin C content of foods (Olmedo et al., 2006); for example boiling destroys about 50% of vitamin C in the food and storage on ships could destroy around 75% of vitamin C (Aufderheide et al., 1998). However, recent clinical study has suggested that scurvy is a "genetic metabolic anomalies" and more than just a nutritional deficiency (Delanghe et al., 2011, 2013).

Clinical manifestation of Scurvy

The recommended vitamin C intake for an individual today is 60-90 mg daily and the total body store of vitamin C in adults is approximately 1500-3000 mg (Hirschmann and Raugi, 1999; Olmedo et al., 2006). However, certain individuals need more vitamin C than others, e.g., smokers, and females during pregnancy and breast feeding (Hirschmann and Raugi, 1999). Clinical studies show that symptoms of scurvy develop very slowly and can appear between 1 and 5 months following vitamin C deprivation, when the body stores decrease to about 300-350 mg; however, children are more at risk than adults (Pimentel, 2003; Olmedo et al., 2006; Larralde et al., 2007; Delanghe et al., 2011). The pathological lesions and severity of manifestation of scurvy depends on the age of individuals and the length of deficiency (WHO, 1999; Delanghe et al., 2011).

Scurvy first affects soft tissues and thus would be absent in archaeological skeletons, but may be present in preserved bodies. The noticeable clinical symptoms of scurvy that can be found in both non-adults and adults are tiredness and lethargy with development of musculoskeletal pain, weakness, bruising and subperiosteal haemorrhage (Figure 4.2), joint swelling, and gingival swelling and bleeding of the gums (Figure 4.3) (Resnick, 1995a; Hirschmann and Raugi, 1999; WHO, 1999; Maat, 2004; Olmedo et al., 2006; Larralde et al., 2007; Velandia et al., 2008; Apostolakos and Halvorsen, 2014). In severe cases of the deficiency the pathological changes affect the growth plates of bones, including costochondral junction of ribs, distal metaphysis of the femur, radius, and ulna, and the proximal metaphysis of the humerus (Resnick, 1995a; WHO, 1999). In the primary stage of pathological changes there is more bone resorption than formation, and thus little or no new bone formation at the growth plate, causing thinning of both the cortex and trabeculae of the spongy bones with increasingly widened spaces evident between the trabeculae (Ortner and Ericksen, 1997; WHO, 1999; Brickley and Ives, 2006). This can cause transverse fractures on the metaphyseal side of the growth plate, producing dislocation of the epiphysis and haemorrhage (Olmedo et al., 2006). However, the vascular tendency to hemorrhage often occurs in the subperiosteal areas in varying degrees, and is more seen in the weight bearing long bones (Figure 4.2), especially the femur and tibia, and the hips, knees and ankles are more at risk (Ortner and Putschar, 1981:270; Fain, 2005; Olmedo et al., 2006; Velandia et al., 2008).

Fig 4.2. Left: pigmentation from repeated cutaneous haemorrhages in the knee joint (Olmedo et al., 2006:Figure 2); right: and on the left leg with spread to the ankle joint (from Velandia et al., 2008:Figure 1)

Many of the manifestations of scurvy resolve within three to five days and most physical signs within one or two weeks purely by introducing vitamin C into the diet (Pimentel, 2003). However, individuals with scurvy often have other dietary deficiencies, which cause some of the clinical abnormalities attributed to scurvy; e.g.,

iron deficiency anemia (Hirschmann and Raugi, 1999; Pimentel, 2003; Murphy and Allen, 2003). Osteopenia is also reported in some individuals with scurvy (Fain, 2005); some individuals may suffer both scurvy and rickets which makes it difficult to differentiate them (Pimentel, 2003).

The earliest documentary record of scurvy goes back to 1249-1250 when French soldiers spent a winter in Egypt (Stuart- Macadam, 1989a). However, due to increasing long sea journeys by sailors at the end of the 16th century scurvy started to attract more attention (Maat, 2004), as it was suggested to have been mainly a maritime problem and not a disease seen on land or during war and famine, since during long sea journeys, sailors did not have access to fresh vegetables and fruits (Mays, 2008a:225). Since then, a growing clinical and archaeological literature has described and reported pathological lesions consistent with this disease among human populations (Wells, 1975; Maat, 1982,2004; Ortner, 1984; Ortner and Ericksen, 1997; Ortner et al., 1999,2001; Melikian and Waldron, 2003; Pimentel, 2003; Brickley and Ives, 2006,2008; Mak and Thirumoorthy, 2007; van der Merwe et al., 2010; Geber and Murphy, 2012).

Paleopathological manifestation of Scurvy

The paleopathological characteristic lesions of scurvy in archaeological bones are bone changes on the skull cortex (frontal bone, parietal bone bosses, mandible, maxilla, greater wing of the sphenoid bone, zygomatic bone, palate, and orbital roof (Ortner, 2003:386-87; Brickley and Ives, 2008). Bone formation and porosity of pelvic, scapula, and the end of long bones are other symptoms of scurvy which can be related to the level and severity of the deficiency (Brickley and Ives, 2008). In adults the skeletal changes are seen mostly as transverse fractures at the costochondral junctions in the ribs, and inflammatory change to the alveolar bone (Figure 4.3) of the jaws as a result of chronic bleeding of the gums which can cause AMTL (ibid, 2008).

Fig 4.3. Left: pathological lesion on an adult mandible, clinical presentation of scurvy in an adult showing periodontal disease and inflammation of the gums (from Pimentel, 2003:Figure 1); right: an archaeological skeleton affected by periodontal disease and suggested as scurvy (from van der Merwe et al., 2010:Figure 2A)

The other changes are bone-loss and osteoporosis in the long bones of the lower limbs and vertebrae which could lead to fractures and might be mistaken for age-related osteoporosis (Resnick, 1995a; Brickley, 2000:187; Brickley and Ives, 2008), and periosteal new bone growth on the long bones as a result of bleeding (Figure 4.4) (Stuart- Macadam, 1989a; Ortner, 2003). However, the appearance of scorbutic bone changes tend to be minor or lessen with increasing age and in adults making it harder to identify this disease compared to non-adults (Brickley, 2000:186). On the other hand, it is also difficult to distinguish the bone changes in scurvy in adults from infectious, traumatic or inflammatory conditions, since they can look similar (Brickley and Ives, 2008). Therefore, for an accurate and reliable diagnosis of scurvy in adult skeletons, a combination of multiple bone changes of scurvy seems necessary. Unfortunately, there are no published literature available with reference to scurvy for past Iranian populations for comparative studies for the current research.

Fig 4.4. Left: subperiosteal new bone formation on the distal tibia, possibly from scurvy (from van der Merwe et al., 2010:Figure 3A); right: black stain from subperiosteal haematoma on the distal tibia around the ankle from scurvy (from Maat, 2004:Plate 3)

(b) Vitamin D Deficiency- Rickets and Osteomalacia

Rickets and osteomalacia are systemic diseases of early childhood and adulthood, respectively, and are caused by inadequate availability of vitamin D, ultimately affecting the skeleton, but not causing death (Pitt, 1995:1885; Resnick and Niwayama, 1995; Kitanaka and Kato, 2000:96; WHO, 2003). Vitamin D is a pro-hormone rather than a traditional vitamin and is essential to human health (Pitt, 1995:1885; Holick and Adams, 1998:123). This vitamin plays an important role in many functions in the body, including immune reactions, protecting lung function, mineral metabolism, cancer

prevention, and promoting growth and general health (Holick, 2008; Holick and Chen, 2008; Valdivielso and Ayus, 2008). Clinical studies suggest that a deficiency in vitamin D may increase the risk of chronic malignancies (e.g., colon, breast), chronic inflammatory and autoimmune disease (e.g. type I, II diabetes), inflammatory bowel disease, and multiple sclerosis (Pitt, 1995; Marvaha and Goswami, 2010:529; El-Hajj Fuleihan, 2010:471). Vitamin D is an important factor in the metabolism and absorption of calcium and phosphorus, which are essential for bone mineralisation. It also affects the activity of osteoblasts and chondrocytes; therefore, the absence of adequate vitamin D results in softening of the bones because of a lack of, or inadequate mineralization (Pitt, 1995; Chaplin and Jablonski, 2009).

Vitamin D is naturally present in some foods such as eggs, milk, liver and oily fish such as salmon, mackerel, sardine, and tuna (WHO, 2003). However, the main source of vitamin D production is in the skin via skin exposure to ultraviolet light (Pitt, 1995; Berry et al., 2002; WHO, 2003; Chaplin and Jablonski, 2009). It is estimated that almost 90% of the vitamin D produced in the body's skin comes from exposure to sunlight (Holick, 2003, 2006). Exposure to sunlight of between 5 and 15 minutes per day during the spring, summer and autumn should generate the minimum required amount of 1000 International Unit (IU) of cholecalciferol (Holick, 2005). The first report of rickets goes back to the 2nd century and the Roman physician Soranus of Ephesus (98-138 A.D) (Aufderheide et al., 1998). Since then many researchers have diagnosed and reported this disease and its risk factors among different living and archaeological populations (Stuart-Macadam, 1989a; Aufderheide et al., 1998; Brickley et al., 2005; Holick, 2005, 2006; Haduch et al., 2009; Unuvar and Buyukgebiz, 2010). Unfortunately, there is no published evidence of vitamin D deficiency from ancient populations from Iran.

Cause of vitamin D deficiency

Factors that affect vitamin D status and cause vitamin D deficiency are suggested to be, for example, lack of sun-exposure, wearing of particular styles of clothing, the type of environment, latitude, and time spent outdoors, skin colour, urbanization, occupational related factors and rising industrial pollution, and also the amount of calcium and phosphorus in the diet (Webb et al., 1988; Pitt, 1995:1898; Littleton, 1998; Mawer and Davies, 2001; WHO, 2003; Chaplin and Jablonski, 2009; Robins, 2009), lead poisoning (Crocetti et al., 2004:222; Dart et al., 2004:1426; and see Ostrander, 2013), pregnancy, and increased age (Chaplin and Jablonski, 2009). Maternal vitamin D

insufficiency affects the foetus and continues to affect the child into infancy and childhood; this may cause growth retardation and also osteoporosis and fractures later in the individual's life period (Cooper et al., 2005; Weisz and Albury, 2013). In addition, there are genetic conditions, malabsorption syndromes and chronic renal disease that can also result in vitamin D deficiency (Kitanaka and Kato, 2000; Hopper, 2000). Underlying secondary hyperparathyroidism may also be accompanied by bone-loss due to the secondary effects of lowered vitamin D on calcium metabolism (Chapuy and Meunier, 1997). It has been observed that the prevalence and severity of rickets and vitamin D deficiency (Figure 4.5) is more common among people eating a vegetarian diet with a "high" amount of wheat cereal and phytate intake and "low" dietary calcium, while individuals with a mixed-diet that includes meat, fish, and milk are less likely to develop rickets and osteomalacia even if sun-exposure is relatively restricted (Ford et al., 1972; Dunnigan and Henderson, 1997; Mawer and Davies, 2001).

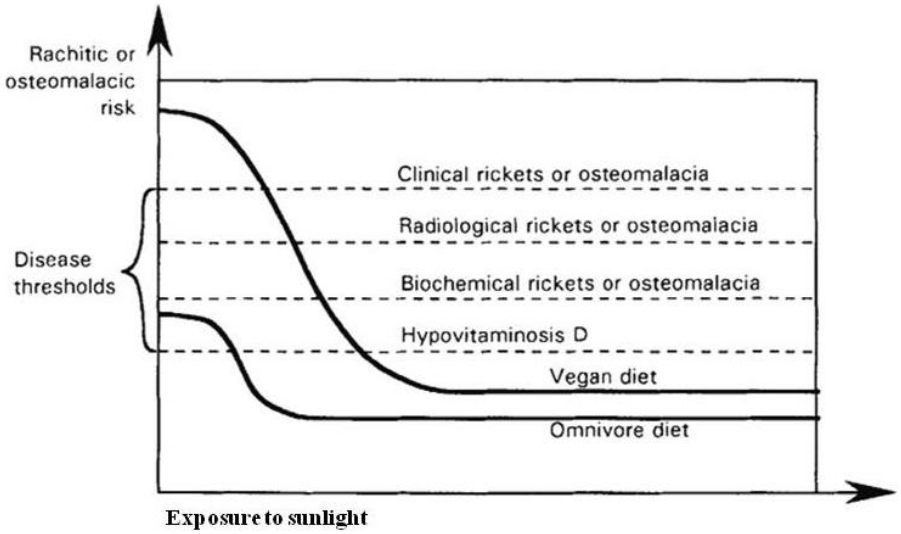


Fig 4.5. Model showing the relationship between exposure to sunlight and the prevalence of rickets and osteomalacia and the disease thresholds (from Dunnigan and Henderson, 1997)

Coarse diets of legumes or dietary fibre (cereals), prevents calcium and vitamin D in the diet from being absorbed (Brickley et al., 2007; Harinarayan et al., 2008), and Dunnigan and Henderson (1997) found that infantile rickets in Ireland increased during the Second World War when consumption rates of cereals increased from 70 to 100%. Modern research in Iran has also shown that there is evidence of rickets in Iranian village children where they consume lots of bread in their diet even though they are exposed to enough sunlight. Recent clinical studies on modern Middle Eastern populations indicate a high prevalence of rickets, osteomalacia, and osteoporosis in this region despite exposure to enough sunlight, suggesting nutritional deficiency of vitamin

D and calcium, life style, a dark skin colour, air-pollution, and low socio-economic status could cause these disorders (El-Hajj Fuleihan, 2010:489; Rahnavard et al., 2010). When interpreting vitamin D deficiency in archaeological populations one has to take into account all these factors.

Clinical manifestation of vitamin D deficiency

When deficiency becomes marked and prolonged, without additional intake of vitamin D via the diet, then "nutritional rickets" occurs in children and juveniles and osteomalacia occurs in adults, with expression of pathological changes on the skeleton (Pitt, 1995; Holick, 2007; Robins, 2009; Rahnavard et al., 2010; Thacher and Clarke, 2011). In rickets, vitamin D deficiency interrupts the deposition of calcium in the growth plate and osteoid during the growing period which causes a delay in bone mineralisation and results in considerable weakening of the skeleton and bone softening (Pitt, 1995; Francis and Selby, 1997; Parfitt, 1998; Berry et al., 2002; Holick, 2003). It is characterized by widening (flaring) of long bone epiphyses (Figure 4.6) and the costal rib ends (rachitic rosary), bowing of the sternum outwards (pigeon breast) or depression in the sternum dorsally (funnel chest), bending of long bones, narrowing of the pelvic outlet, and skull thickening, that can even continue throughout adulthood (Pitt, 1995; Holick, 2005; Robins, 2009). Bowing of the legs, spinal kyphosis, and short stature can be seen in advanced cases of rickets (Aufderheide et al., 1998; Holick, 2005). DEH and caries can also be severe in rickets (Stuart-Macadam, 1989a). Vitamin D deficiency in adults known as "osteomalacia"; causes incomplete or poor mineralization of osteoid and spongy bone, leading to a generalised softening and weakening of the skeleton, and bone deformity and pseudo-fractures (Pitt, 1995; Holick, 2007; Thacher and Clarke, 2011). Since, the manifestation of vitamin D deficiency directly affects bones; all the clinical signs mentioned above can be recognized in skeletal remains.

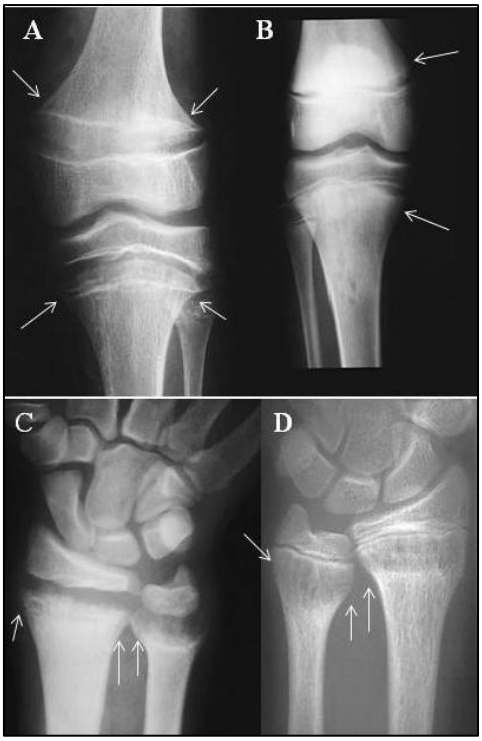


Fig 4.6. A and B: radiographs showing widening and cupping of long bone epiphyses due to rickets (knees of adolescents with high and mild vitamin D deficiency); C and D: wrist of an individual with vitamin D deficiency before and after treatment (from Adams, 2005:Figures 2-3)

Paleopathological manifestation of vitamin D deficiency

Rickets has been recognized and reported in many archaeological populations (Mays et al., 2006a,2009; Robins, 2009; Haduch et al., 2009), but osteomalacia less so. Osteomalacia affects the entire skeleton (Ortner, 2003), but mostly the weight-bearing bones of the axial skeleton where normal movement and muscle function are affected (Roberts and Cox, 2003; Brickley et al., 2005), and bones with a high remodelling rate, such as the ribs, vertebrae, sternum, and pelvis (Ortner, 2003; Brickley et al., 2005). Pseudo-fractures (Looser's zones) are an important expression of osteomalacia (Figure 4.7) and are likely to be recognisable in archaeological bones. It has been suggested that they develop from related stress fractures which fail to heal (Brickley et al., 2005). They occur at specific regions of the skeleton, such as the medial cortex of the neck of femur and the medial sub trochanteric region of the femur, the neck of the humerus, superior and inferior pubic rami, ribs, and the lateral margins of the scapula (Ortner, 2003:399; Brickley et al., 2005).

Fig 4.7. Left: pseudofractures affecting the cortical bone surface of the spinous process of the scapula in an adult with osteomalacia; right: compression of vertebral body with loss of spongy bone as a result of osteomalacia (from Brickley and Ives, 2008:Figure 5.17, 5.19)

Manifestations of childhood rickets can be continued into adulthood and seen in adults who previously suffered from rickets; this is called "residual" or "healed rickets" (Brickley et al., 2005; Waldron, 2009:129). Deformities in bones are the most likely candidates for survival and recognition in the adult skeleton and particularly those of the legs (Figure 4.8) (Brickley et al., 2010). For example, Brickley and colleagues (2010) investigated the pattern of residual rickets in 135 skeletons from St Martin's, Birmingham, England. They noticed that the pattern of residual rickets deformities recorded in adults was very similar to those recorded in children with rickets. It is suggested that with increasing age and in older individuals, however, the pathological changes of vitamin D deficiency in the skeleton may be quite subtle, particularly in individuals who had childhood rickets. Therefore, the skeletal pathological changes could be confusing and difficult to differentiate between age related osteoporosis, osteomalacia, or residual rickets (Parfitt, 1998:398; Brickley et al., 2005). For example, when long bone bending deformities are present it may not be easy to differentiate between residual rickets and osteomalacia, but where pseudo-fractures of the femoral neck and subtrochanteric region occur, the bending deformities would be suggestive of osteomalacia (Brickley et al., 2005). On the other hand, it is often difficult to determine clearly whether bending of bones is due to disease or a manifestation of normal morphological variation (Mays, 2008a:220).

The occurrence and manifestation of vitamin D deficiency in past populations, whether in children or adults, can provide important information about life style, socio-economic, cultural, environmental, and nutritional factors affecting individuals (Ortner and Mays, 1998; Brickley et al., 2007, 2010; Brickley and Ives, 2008). However, it

should be noted that better understanding and accurate recognition and recording of pathological lesions of vitamin D deficiency are important (Brickley et al., 2010).

Fig 4.8. Left: healed rickets in an adult femur; right: deformities in the left and right tibiae related to residual rickets (from Ortner, 2003:Figures 15-27 and 15-28)

(c) Osteopenia or Osteoporosis

Osteoporosis is the most common of the skeletal metabolic diseases observed in both living and archaeological populations (Resnick and Niwayama, 1995; Turner-Walker et al, 2001; Cho and Stout, 2003:207; Marcus and Bouxsein, 2013). This chronic disease is becoming one of the most common diseases affecting millions of people (Matkovic and Landoll, 2004). It is a systemic disease characterised by a decrease in bone mineral density (BMD) and bone mass that leads to weakened bones and a heightened risk of fracture, even with a minimal trauma (Ferrari et al., 2000:45; Christodoulou and Cooper, 2003; Kanis et al., 2004; WHO, 2007; Holick, 2007; Waldron, 2009:118). The other "definition" for osteoporosis is "osteopenia" or low bone mass. Osteopenia refers to a decrease in BMD but this is not as low as for osteoporosis, and without risk of fracture (Resnick and Niwayama, 1995:1785; WHO, 2003). Osteoporosis is the most common development of osteopenia where natural bone-loss has been exceeded and the individual may suffer from one of the related fractures (Gallagher, 1990; Resnick and Niwayama, 1995:1785). The World Health Organisation

(WHO, 2007) has defined osteoporosis and osteopenia relative to the young adult reference mean, so individuals with bone density values between -1 and -2.5SD below that mean have osteopenia or low bone density, and those with values more than 2.5SD below have osteoporosis (WHO, 2003,2007; Eastell, 2005; Waldron, 2009:119).

Causes of osteopenia or osteoporosis

Clinical studies show multiple factors impair peak bone density being achieved during childhood and adulthood (Resnick and Niwayama, 1995), and include an inherited predisposition, malnutrition particularly in early life, low calcium intake, vitamin D and C deficiency, intestinal illness and parasites that inhibit calcium and vitamin D absorption, chronic diseases, inflammatory diseases (e.g., rheumatoid arthritis), cancer, secondary hyperparathyroidism, toxins (e.g., lead), delayed puberty, cigarette smoking, caffeine and alcohol, a sedentary lifestyle, many pregnancies, prolonged lactation, aging, and hormonal differences in males and females. All may affect the achievement of peak bone density and increase the risk of osteopenia and osteoporosis (Resnick and Niwayama, 1995; Ross, 1996; Nguyen and Eisman, 1999; Ferrari et al., 2000:46; Prelevic, 2001; WHO, 2003; Matkovic and Landoll, 2004; Rauch and Glorieux, 2004; Eastell, 2005; Blahoš, 2007; Marcus and Bouxsein, 2013). It is suggested that maternal vitamin D deficiency also can affect the foetus by reducing bone mineral acquisition during intrauterine development, resulting in low birth weight and poor childhood growth and osteopenia or osteoporosis (Cooper et al., 2005).

Clinical manifestation of osteopenia or osteoporosis

Clinical studies show that a reduction in bone mass of more than 25-30% causes osteoporosis (Resnick and Niwayama, 1995; Stevenson and Marsh, 2007:35), and it is associated with an increase in morbidity and mortality today (Cho and Stout, 2003:207). Osteoporosis can be classified into two types, “primary” and “secondary”. Primary osteoporosis is further classified into two types with different epidemiological and pathological features. Type I is frequently seen in females after the menopause, also called postmenopausal osteoporosis, and is associated with “trabecular” bone-loss, and identified via “Colle’s”, hip and vertebral compression fractures (Resnick and Niwayama, 1995; Hodge, 2004; Eastell, 2005) (Figure 4.9). Risk factors that contribute to the development of primary osteoporosis are suggested to be sex, age, low bone mass (osteopenia), prolonged immobilization, but a low dietary calcium intake and vitamin D

deficiency are also important (Resnick and Niwayama, 1995; Christiansen, 1995; WHO, 2003; Stevenson and Marsh, 2007:23). Type II, or senile osteoporosis (serious bone-loss), related to increasing age and affects both males and females after age 60 and is characterised by both "cortical" and "trabecular" bone-loss, including thinning of the cortex and an increase in cortical porosity, identified via hip and vertebral fractures (Resnick and Niwayama, 1995; WHO, 2003; Schultz, 2003:175). Medical research demonstrate that with increasing age and with hormonal changes the process of bone remodelling becomes unbalanced with too much bone resorption or too little bone formation, which ultimately diminishes bone mass (Seeman, 2000:16; Eastell, 2005). Clinical studies also show that skeletal fragility is greater in women than in elderly men, because women lose bone faster (Resnick and Niwayama, 1995; Seeman, 2000:14; Kanis et al., 2004).

Secondary osteoporosis can be seen in all age-groups and affects both sexes equally. This type is more related to other metabolic diseases such as scurvy, chronic malnutrition and dietary imbalance, and other pathological conditions (see above) which account for less than 5% of all osteoporosis cases (Resnick and Niwayama, 1995; Schultz, 2003:175; Waldron, 2009:121).

Fig 4.9. Left: radiograph of a proximal femur hip fracture; right: radiograph of a distal radial (Colles) fracture (from Stevenson and Marsh, 2007:Figures 5.3 and 5.5)

As the spongy/trabecular bone is more affected in osteoporosis, therefore, this condition does not affect the entire skeleton (Resnick and Niwayama, 1995:1785). The regions of the skeleton that are more susceptible to fracture, due to osteoporosis, are those bones that contain a great deal of trabecular bone, including the hip (the femoral neck), wrist (Colle's fracture) (Figure 4.9), spine (leading to kyphosis), ribs, sternum, and pelvis (Resnick and Niwayama, 1995; Kanis et al., 2004; Eastell, 2005; Waldron, 2009:118). Osteopenia also shows similar signs to osteoporosis, but with smaller

reductions in bone mass than osteoporosis and with less bone fragility and susceptibility to fracture (WHO, 2003, 2007).

Paleopathological manifestation of osteopenia or osteoporosis

The clinical manifestations of osteopenia and osteoporosis can be recognized in archaeological remains (Agarwal and Grynpas, 1996; Brickley, 2002). The first characteristic feature of osteoporosis might be the weight of affected bones which are much lighter than other similar bones of the same size/sex/age from other burials from the same site (Ortner, 2003:410). However, Brickley and Agarwal (2003) argue that the weight of bone in archaeological samples is not sufficient to diagnose osteopenia or osteoporosis as there are many different diagenetic changes that make bones lighter and influence the accurate diagnosis of this disease. However, this condition is manifested in skeletal remains by two features, thinning of the cortex of the long bones and reduction in the spongy bone (Figure 4.10) (Brickley, 2002; Ortner, 2003:412), as seen in clinical cases (see above).

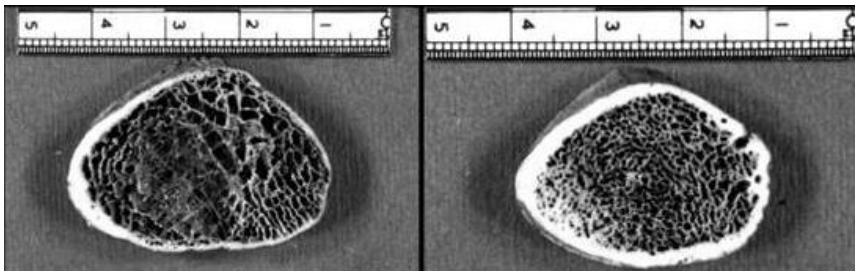


Fig 4.10. Sections from the femoral neck (left) of old (50+) and (right) a young (15-25) archaeological individuals illustrating the difference in both cortical and trabecular bone with increasing age (from Brickley, 2002:Figure 3)

Colle's fracture and femoral neck fractures can be recognised in archaeological skeletons as well (Figure 4.11) (Brickley and Ives, 2008). Osteoporosis is more severely manifested in the vertebral bodies, with decreasing density of trabecular bone resulting in compression fractures, wedge vertebrae (Figure 4.12) and secondary kyphosis (Aufderheide et al., 1998; Brickley, 2002; Ortner, 2003:411). However, it should be considered that not all such fractures are related directly to osteoporosis, although a large number of those in the elderly, particularly in women, are likely to be (Brickley, 2002).

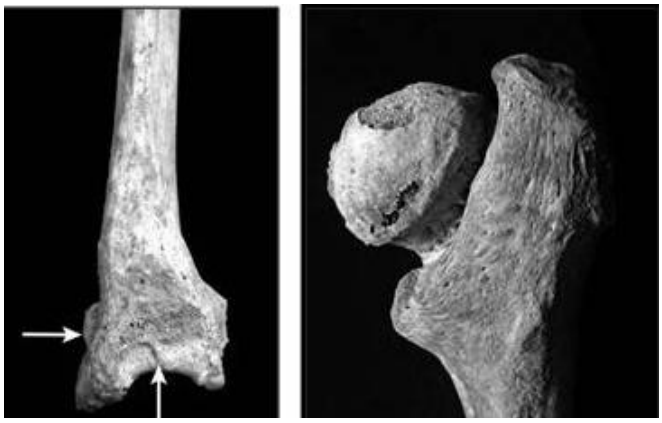


Fig 4.11. Colles' fracture (left) and fracture of the femoral neck (right) occurring with age related osteoporosis (from Brickley and Ives, 2008:Figures 6.4 and 6.6)

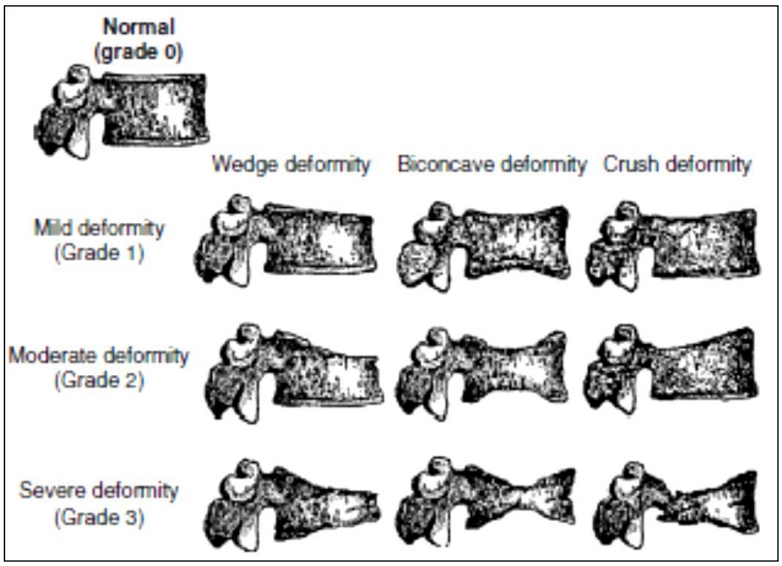


Fig 4.12. Schematic image of vertebral deformities as a result of possible age related osteoporosis (from Brickley and Ives, 2008:Figure 6.5)

4.1.2. Dental Indicators

Teeth are the hardest tissue of the body and can survive well to be excavated from archaeological cemeteries. They are one of the most important parts of any bioarchaeological analysis and can provide valuable information about health and disease in the past (Eshed et al., 2006; Temple and Larsen, 2007). Dental disease is among the commonest diseases reported from archaeological sites (Roberts and Manchester, 2005:63). It provides important clue to levels of biological stress and poor health, oral-hygiene, nutritional status, subsistence patterns, food preparation techniques, and overall lifestyle of past individuals and populations and has been used in much bioarchaeological research (Smith, 1984; Walker and Erlandson, 1986; Larsen et al., 1991; Lukacs, 1992; Littleton and Frohlich, 1993; Fearne and Brook, 1993; Larsen, 1995; Strohm and Alt, 1998; Keenleyside, 1998; Schollmeyer and Turner, 2004;

Chamberlain, 2006:162; Lieverse et al., 2007; Lanfranco and Eggers, 2010; Eshed et al., 2010).

This research observed pathological indicators of dental stress including DEH, as well as dental disease including caries, calculus, periodontal disease, periapical lesions, AMTL, and tooth wear.

(i) Dental Enamel Hypoplasia (DEH)

Enamel formation

Enamel forms from linked sheets of cells called ameloblasts (Hillson, 1996:148; Bartlett, 2013); is made up of small calcium phosphate crystallites and forms the exterior surface of the tooth crown (Bassim et al., 2009). Enamel formation starts on the occlusal surface of the crown and then proceeds down the sides of the crown, extending to the cervix/cemento-enamel junction, when the crown is complete (Hillson, 1996:114). It is a hard strong and durable tissue that cannot be remodelled or altered during life. The formation of enamel is a continuous and unified process that is very "sensitive" to any physiological disruptions which may either slow or stop its growth (Bassim et al., 2009). Because these effects are permanent, defects can provide an excellent record of stress and growth disturbance during tooth crown formation in the first 11 to 12 years of childhood, both in past and present human populations (Goodman and Rose, 1990, 1991; Pascoe and Seow, 1994; Larsen, 1997:44; Reid and Dean, 2006; Ogden, 2008:284; Masumo et al., 2013; Salanitri and Seow, 2013).

Types of enamel defects and their formation

Enamel hypoplasia is the most common group of enamel defects that can occur (Hillson, 1986:129). It is defined as a deficiency in the amount of enamel due to a disturbance during the critical time of enamel formation and mineralization, and its position on the crown is often used to reflect the timing of the illness or nutritional stress during childhood (Suckling, 1989; Skinner and Goodman, 1992:156; Bassim et al., 2009). Hypoplastic features (Figure 4.13) appear as a single or multiple continuous lines (LEH), grooves, furrows, and depressed pits, with varied depths around the circumference of the tooth crown. These defects are observable macroscopically (Goodman and Rose, 1990, 1991:281; Hillson, 1996:166-7; Hillson and Bond, 1997). Such a defect is considered to be a non-specific indicator of systemic physiological stress in a particular period in the growth of the individual (Goodman and Rose,

1990,1991; Duray, 1996; Guatelli-Steinberg and Lukacs, 1999; Bassim et al., 2009; Masumo et al., 2013).

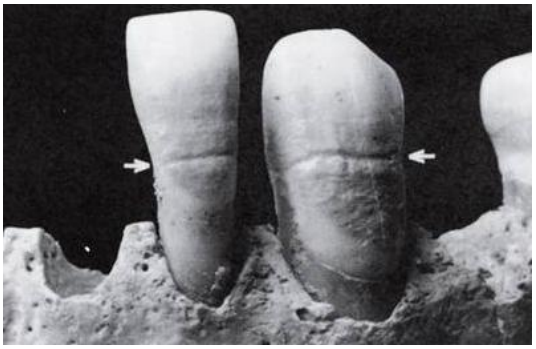


Fig 4.13. Ridges of hypoplastic defects in the enamel (arrows) on canine and incisor teeth (from Mays, 1998:Figure 7.6)

The formation of a defect depends on the nature and severity of the disruption and also on the phase of maturation of the tooth crown, with certain periods of maturation being more vulnerable than others (Buikstra and Cook, 1980). Griffin and Donlon (2009) demonstrated that the aetiology of different enamel hypoplastic defects is different; e.g., a simple pit is usually as a result of trauma, while linear enamel hypoplasia and arrays of pits are caused by systemic stress such as malnutrition or disease. Because enamel is continuously deposited during a crown's growth, the hypoplastic line's width can provide data about the duration of the "stress" according to whether it lasted weeks or months (Ensor and Irish, 1995; Larsen, 1997:49). Hubbard et al. (2009) found that the average hypoplastic line's width is a more accurate measure of the duration of stress when determined at a population rather than individual level. In general, the severity and intensity of the disruption (disease) has a direct effect on the type and size (width and depth) of hypoplastic lesions (Goodman and Armelagos, 1985; Goodman and Rose, 1990:Figure13; Duray, 1996). Blakey and Armelagos (1985) suggested that a narrow hypoplastic line indicates a short term deficiency, while a wider "band" indicates a long term defect.

There is a considerable difference in susceptibility and sensitivity to defects on certain areas of tooth crowns and specific teeth of individuals (Goodman and Armelagos, 1985; Skinner and Goodman, 1992:162-3; Saunders and Keenleyside, 1999). For example, anterior teeth (incisors and canines) are more sensitive to stress than premolars and molars, and hypoplasia is usually more common and pronounced on these teeth (Goodman and Armelagos, 1985; Goodman and Rose, 1990; Steckel et al., 2005). The cervical and middle thirds of the tooth crowns are more susceptible to

disruption when they are developing and provide the most data on stress (Goodman and Armelagos, 1985; Larsen, 1997:46; King et al., 2005). However, different frequencies of enamel hypoplastic on different teeth may be associated to variation in the timing and duration of tooth crown formation (King et al., 2005). Histological studies of dentine suggest that enamel layers forming the surface of a tooth crown may hide earlier enamel depressions and therefore the enamel defect in that region of the tooth will not show macroscopically, resulting in the under-recording of frequency of DEH (Hillson and Bond, 1997; Ogden, 2008:284). On the other hand, tooth wear and reduction in crown height, particularly in adults over 40 years, can remove hypoplastic evidence, so it is impossible to record and establish hypoplastic chronologies in teeth with heavy attrition (King et al., 2005).

Causes of enamel defects

Various "stressors" such as chromosomal anomalies, neonatal disturbances, infectious diseases such as syphilis, nutritional deficiencies, metabolic disorders, and childhood fevers; all may disturb ameloblast production and cause enamel hypoplasia to occur (Sciulli, 1978; Pascoe and Seow, 1994; Hillson et al., 1998; Boldsen, 2007; Bassim et al., 2009; Masumo et al., 2013; Salanitri and Seow, 2013; Memarpour et al., 2014). In general, it is believed that three factors may cause DEH: systemic metabolic stress, inherited anomalies, and localized trauma (Goodman and Rose, 1991:281). Metabolic stresses (e.g., deficiencies of vitamin D, vitamin A and protein malnutrition) that affect the body during childhood usually slow or stop enamel growth in the parts of the crown affected by deficiency during crown formation (Moynihan and Petersen, 2004). However, defects resulting from an inherited predisposition (e.g., amelogenesis imperfecta) affect both permanent and deciduous crowns and lead to the most severe defects, but this is rare (less than 1%) in human populations (Goodman and Rose, 1990, 1991:281). Trauma or other localized factors disrupt the formation of only one tooth or a few neighbouring teeth (Buikstra and Ubelaker, 1994:56). Although the exact cause of enamel defect development is not well understood, it is known that hypoplastic defects are more related to periodic physiological stresses, impacting on to matrix secretion during dental development (Ritzman et al., 2008).

Hypoplastic defects have been studied, described and recorded among living and archaeological populations, focusing on frequency, duration or severity and size, position on the tooth surface and age at formation (Rose, 1977; Sciulli, 1978; Rose et

al., 1978; Goodman et al., 1980,1984,1987; Martin et al., 1984; Smith et al., 1984; Rathbun, 1984; Blakey and Armelagos, 1985; Lanphear, 1990; Goodman and Rose, 1990,1991; Hillson, 1992; Pascoe and Seow, 1994; Ensor and Irish, 1995; Duray, 1996; Stodder, 1997; Hillson and Bond, 1997; Saunders and Keenleyside, 1999; King et al., 2002,2005; Ogden, 2008; Griffin and Donlon, 2009; Masumo et al., 2013). In the permanent dentition enamel defects usually record developmental disturbances occurring between about eight months to seven years of age and if the third molar is erupted then it presents information from approximately nine to 13 years of age (Skinner and Goodman, 1992:163-4 Table 3, Figure 6). The occurrence of enamel hypoplasia between the ages of two and four years may be associated with weaning (Skinner and Goodman, 1992:167).

Recording

Various recording methods for classifying DEH have been developed (Goodman et al., 1980; Buikstra and Ubelaker, 1994:56; Duray, 1996). The standard scoring method for Developmental Defects of Enamel (DDE) was designed (1982) by the Fédération Dentaire Internationale (FDI) Commission on Oral Health (Hillson, 1996:172). This classification system divided hypoplastic defects into four types: pits (type 3), horizontal grooves (type 4), vertical grooves (type 5) and total absence/missing of enamel (type 6). The number and demarcation of hypoplasias were divided into two groups: single or multiple, and the location of the defect on the tooth was divided into sections as: gingival half, incisal half, occlusal, cuspal and whole surface (Hillson, 1996:174 Table 6.2). This system also describes discoloration and opacities of teeth. Nevertheless, because post-mortem changes may affect the colour of teeth in archaeological samples, it should be noted that differentiating ante-mortem and post-mortem colour changes can be challenging. This method of classification has been used widely and recommended in a number of modern and archaeological studies as a reliable standard (Hillson, 1986:132; Goodman et al., 1987; Goodman and Rose, 1990; Skinner and Goodman, 1992:158; Hillson, 1996:172; Santos and Coimbra, 1999; King et al., 2002, 2005; Griffin and Donlon, 2009). Developmental disturbances on enamel resulting from stress usually affect the part of the tooth that is in the process of forming, so the location of an enamel defect on a tooth may provide information about the timing of the disturbance (Goodman et al., 1980; Larsen, 1997:48). Thus, given the chronology of enamel formation, it is thought possible to calculate crown formation times precisely

to give ages on a scale of days and weeks rather than just months and years (Reid and Dean, 2006).

There are several methods that have been developed for assessing the timing of growth disturbances (Goodman et al., 1980, 1984; Buikstra and Ubelaker, 1994:56-57). Goodman and colleagues (1980) developed a system for studying the age of enamel defect formation related to the crown-formation schedules of Massler and co-workers (1941) and based on the mineralization time of the enamel for each tooth (Goodman et al., 1980). In this method the distance from the cemento-enamel junction (CEJ) to the most occlusal portion of each hypoplasia is measured, providing the age of defect formation between birth and age seven (ibid). But, Reid and Dean's (2006) dental development sequence translates to ages between birth and 11 to 12 years. However, the time of dental growth and enamel formation vary between different teeth; they also may vary among individuals and populations with difference genetic background, environment, social status, and diet (lukacs, 1989:267; Hillson, 1996:140-1).

In general, the presence of DEH provides significant information about poor diets and disease during enamel development (Rose et al., 1985) and, when coupled with the other skeletal lesions such as PH, metabolic bone disease, and growth retardation, it can provide insight into systematic stress experienced by individuals during growth (Goodman et al., 1988, 1991:290). Unfortunately, there is little published evidence of DEH from the ancient populations of Iran (Rathbun, 1984:152; Hemphill, 2008). For example, the Neolithic period Ganj Dareh (8500-7000 B.C.), 6% of individuals exhibited DEH, but the average frequency was 14% (individuals affected) among Bronze and Iron Age populations, and at Dinkha Tepe (1900-800 B.C.) there was a higher frequency of DEH (77%- Rathbun, 1984:152). Hemphill (2008) studied a total of 235 dental individuals from *Tepe Hissar*, investigating association between dental disease, health, disease and wealth. In this study there was no division between periods, but he noted that females had a higher frequency compared to the males. The data also showed that wealthy individuals experienced a higher prevalence of DEH than poor individuals.

(ii) Dental Caries

Dental caries or tooth decay is a disease with a bacterial origin (Duckworth and Huntington, 2006:1) that causes demineralization and destruction of the dental hard tissues (enamel, dentin and cementum) (Selwitz et al., 2007). Dental caries is one of the

most prevalent chronic diseases of people worldwide (ibid, 2007). Caries is also the most common dental lesion reported from archaeological assemblages (Hillson, 2008a:111). It is mainly accepted as an indicator of the amount of carbohydrate, especially sugars consumed by an individual (Turner, 1979; Navia, 1994; Petersen, 2003). Caries may appear as a small white or brown opaque spot on the tooth enamel, or large cavities in the teeth (Hillson, 2002:269; Pitts, 2004; Selwitz et al., 2007; Rindal et al., 2012). The destruction of the tooth structure occurs due to acid production by bacteria in dental plaque, as a result of fermentation of food sugars in the diet (Moynihan and Petersen, 2004; Hillson, 2005:290) which dissolves the dental tissue (Hillson, 2002:272; Selwitz et al., 2007). Untreated, caries can extend into the dentine and eventually the secondary dentine and the pulp cavity. This can result in infection and destruction of the alveolar bone, leading to an abscess, and remodelling with ultimate tooth loss (Selwitz et al., 2007). Therefore, it is important to consider AMTL when studying dental caries, although it is difficult to determine the cause of tooth loss and whether lost teeth had caries (Hillson, 2008b:317). Carious lesions (Figure 4.14) can develop in both the crown (coronal surface) and root surfaces (cemento-enamel junction) of deciduous and permanent teeth (ibid, 2008:315). Molars and premolars are more at risk of caries than the anterior dentition because of their complex morphology and grinding function (Walker and Erlandson, 1986; Larsen et al., 1991; Hillson, 2005:297).

Fig 4.14. Dental caries of the right mandibular molar (from Ortner, 2003:590)

Dental caries prevalence rates are determined by a multifactorial aetiology including genetics, diet, sex, age, pathogenic agents, enamel elemental composition, DEH, saliva, and absence of oral-hygiene (Figure 4.15) (Navia, 1994; Woodward and Walker, 1994; Saunders et al., 1997; Hillson, 2002:278; Selwitz et al., 2007; Vargas-Ferreira et al., 2014). Daneshkazemi and Davari (2005) examined 1223, 12 years old students from Iran; they observed a significant association between dental caries (74.7%) and DEH (32.7%).

Vitamin D deficiency and nutritional stress particularly during childhood will affect the tooth development and increase the risk of caries (De Paola et al., 2006:1156). In addition, other factors such as periodontal disease and resorption of the alveolar bone (particularly with aging) can expose the roots to cariogenic bacteria and cause caries of the root (Hillson, 2002:282; Selwitz et al., 2007). Food preparation techniques are one of the important factors that affect dental caries frequencies; e.g., processing of food with grinding stones may introduce abrasive materials and cause rapid wear during consumption (Larsen, 1987), and make the teeth more susceptible to caries. However, it is also suggested that dental wear may decreases or remove caries lesions by removing the vulnerable occlusal fissures and lead to fewer carious lesions (Maat and Velde, 1987). Nevertheless, heavy dental attrition in archaeological skeletal remains may make it difficult to determine exactly whether or not a tooth was originally carious (Hillson, 2005:295). Fluoride naturally occurring in food and water is known to protect teeth from cariogenic activity (Larsen et al., 1991; Sealy et al., 1992; Navia, 1994).

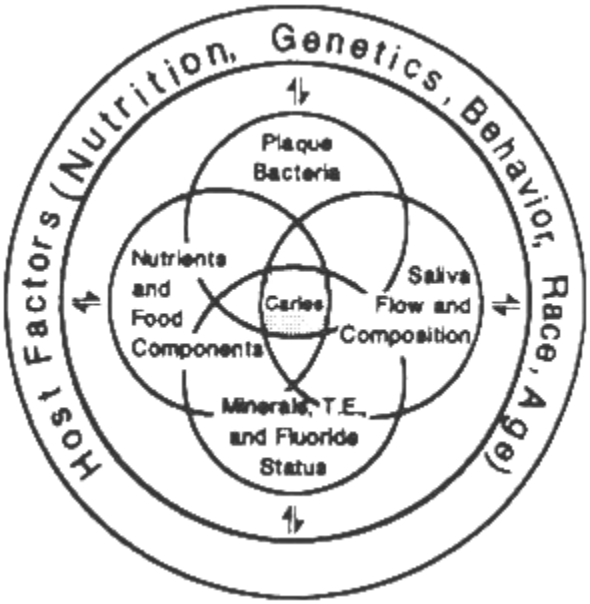


Fig 4.15. Illustration of the factors involved in the dental caries process (from Navia, 1994:Figure.1)

Dental caries, with DEH, are clearly indicators of diet and stress (Temple, 2007). Numerous studies show that the prevalence of caries is higher among agriculturists than hunter gatherers (Turner, 1979; Jurmain, 1990; Adler and Turner, 2000), and a diet heavy in starch rich plants and sugar (carbohydrate) is linked with caries (Cohen and Armelagos, 1984; Hillson, 1986, 2002:283; Larsen et al., 1991; Larsen, 1995; Schollmeyer and Turner, 2004; Temple and Larsen, 2007). However, the frequency of caries is very low among populations with a diet rich in animal fat/protein, and marine

foods with little or no carbohydrate (Sealy et al., 1992; Schollmeyer and Turner, 2004; Hillson, 2008a:112). It is suggested that the prevalence of caries among agricultural populations is affected by two factors, malnutrition affecting tooth development and a higher carbohydrate content in the diet (Ortner, 2003:591). Unfortunately, there is little published evidence of the frequency of dental caries available from the ancient populations of Iran (e.g., Hemphill, 2008).

(iii) Calculus

Dental calculus (Figure 4.16) occurs in the majority of adults worldwide (White, 1997). Calculus is the result of mineralization of plaque on the teeth (ibid,1997) and it usually survives well on archaeological human teeth (Ortner and Putschar, 1981; Hillson, 2002). However, it is vulnerable to post-mortem damage and can easily be broken and separated from teeth, affecting the accuracy of recording of calculus. Two types of calculus have been recognized in modern and archaeological population, supragingival and subgingival (White, 1997; Roberts-Harry and Clerehugh, 2000; Hillson, 2008b:312). Calculus on the crown or root surface above the gum margin is known as supragingival; this is frequently found in archaeological skeletal remains (Hillson, 2002, 2008a:312; Duckworth and Huntington, 2006), and is usually white, yellow or light brown in colour (Chamberlain, 2006:164; Waldron, 2009:241). Calculus on the surface of the roots in periodontal pockets and below the gum margin is known as subgingival calculus, which is much thinner and less obvious (Hillson, 2008b:312). Calculus can cause periodontal disease, alveolar resorption, and AMTL (Lieverse, 1999; Delgado-Darias et al., 2006; Jowett et al., 2013). The aetiology of dental calculus formation and mineralization are little understood (Hillson, 2008b:312). Diet has been associated with dental calculus, e.g., it is more common among individuals with a diet rich in protein and low in carbohydrate but non-dietary cultural practices such as poor oral hygiene, chewing abrasive materials, and the use of teeth as tools, are also important and can increase or decrease the extent of calculus formation (Lieverse, 1999; Arabaci et al., 2013). Alternatively, an agriculturally based diet has been associated with a high frequency of calculus (Hillson, 1979; Eshed et al., 2006), and White (1997:508) suggested that calculus formation is population specific and affected by ethnic origin, diet, age, oral-hygiene habits, and access to professional care. There are few published reports on the frequency of dental calculus available from the ancient populations of Iran (Hemphill, 2008).

Fig 4.16. Dental calculus on the maxillary and mandibular teeth (from Ortner, 2003:Figures 23-10)

(iv) Periodontal Disease

Periodontal disease or periodontitis reflects bacterial inflammation of the gums (gingivitis) and destruction of the alveolar bone surrounding the teeth (Pihlstrom et al., 2005; Selwitz et al., 2007). Inflammatory cells destroy the collagen fibres in the gingivae and began to destroy the alveolar bone adjacent the tooth (Figure 4.17); ultimately when too much bone is lost, there is less support for the teeth and they may be lost (Pihlstrom et al., 2005; De Paola et al., 2006:1171). This condition is accompanied by soreness, pain, tooth sensitivity and mobility (De Paola et al., 2006:1171). The aetiology of periodontal disease is complex, but many bacteria found in dental plaque and variations in host immune are linked to the occurrence of this disease (Watts et al., 2008). Metabolic disease (scurvy) and the susceptibility of gums of affected individuals to bleed may also cause periodontal disease (Waldron, 2009:240; Gokhale et al., 2013). On the other hand, dental wear, caries, mechanical irritation, periapical lesions, or a lack of oral-hygiene can expose the pulp cavity and cause severe periodontal disease (Slewitz et al., 2007). Periodontal disease has a major role in AMTL in humans, especially of the molars, and is associated with increasing age (Hillson, 2008b:321; Petersen, 2003; Lieverse et al., 2007). Between 5 and 15% of most modern populations and about 2% of youth in the world experiencing tooth loss due to severe periodontal disease (Petersen, 2003; Richards, 2014). In archaeological dentitions periodontal disease can be recognised by evidence of pitting, new bone formation, remodelling and resorption of the alveolar bone margins, creating an abnormally large distance between the alveolar bone level and the cemento-enamel junction (CEJ) (Brothwell, 1981; Ogden, 2008; Waldron, 2009:240).

Periodontal disease has been associated with diet (Larsen, 1997). For example, Costa (1980, 1982) studied the prevalence of dental disease in three prehistoric Eskimo populations from Alaska who consumed a diet based on a high animal protein/fat and low-carbohydrate content. His data showed very low rates for caries and periapical lesions, but very heavy occlusal wear and mild and severe periodontal disease. He associated these findings with a diet lacking in sugars and starches. Larsen (1997) found a correlation between increased carbohydrate consumption and periodontitis. Enwonwu (1995) noticed that poor dietary practice and malnutrition can affect an individual's immune response and oral-health, which consequently cause rapid progress in periodontal disease.

Severe periodontal disease is further suggested to be associated with diabetes (Petersen, 2003) and with increased risk of cerebrovascular and cardiovascular disease mortality in many studies, along with Alzheimer's disease (Pihlstrom et al., 2005; Watts et al., 2008). Unfortunately, there are few published reports of the frequency of periodontal disease available from the ancient populations of Iran (Hemphill, 2008), regardless of the correlation between diet/subsistence economy and dental health.

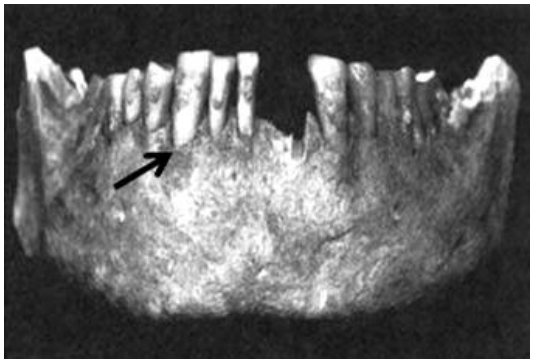


Fig 4.17. Periodontal disease related exposure of the roots of the anterior teeth (from Ortner, 2003:Figures 23-8)

(v) Periapical Lesions

Periapical lesions, or dental abscess, or pulpitis is defined as inflammation of the pulp cavity which develops following exposure of the cavity, and entry of bacteria; this can occur with dental caries, attrition, dental fracture, lack of dental hygiene, and periodontal disease (Soames and Southam, 2005; Donoghue, 2008; Ogden, 2008; Waldron, 2009:241). The toxins of the bacteria pass directly into the pulp and cause pressure inside the alveolar bone. Blood vessels are compressed, inflammation begins and local pulp death occurs. If not treated then it lead to death of the entire pulp cavity and a hole or sinus on the surface of the alveolar wall (granuloma/cyst or abscess- see

Ogden, 2008) develops, with eventual tooth loss (Hillson, 2002:284; 2005:310- Figure 4.18). In some cases the infection may release organisms into the blood and cause septicaemia, seriously threatening the life of the individual (Donoghue, 2008; Waldron, 2009:243; Shweta and Prakash, 2013).

Fig 4.18. a: cystic lesions related to premolars and molars; b: granulomas above the roots of two teeth (from Ogden, 2008:Figure 13.8); c: dental abscess associated with a first mandibular molar (from Klaus and Tam, 2010:Figure 4B)

(vi) Ante-Mortem Tooth Loss (AMTL)

AMTL is when a tooth has been lost before an individual's death (Lukacs, 1981). The etiological pathways include trauma, the use of teeth as a tool, advanced dental caries or dental wear, periodontal disease, and nutritional deficiency (scurvy), as well as aging and osteoporosis of the alveolar bone (Petersen, 2003). However, it is suggested that periodontal disease is the major cause of tooth loss, as discussed above (Oliver and Brown, 1993; Petersen, 2003; Hillson, 2008b:321; Waldron, 2009:238). Lorentz (2010) found a link between the high prevalence of AMTL (15%) and dental wear (31%) among 37 individuals from Shahr-i Sokhta, Iran (3rd millennium B.C). Nevertheless, when tooth loss occurs before death, there is usually evidence of alveolar bone resorption and bone remodelling in the socket (Figure 4.19), but no such evidence where the loss occurred after death (post-mortem) (Waldron, 2009:238).

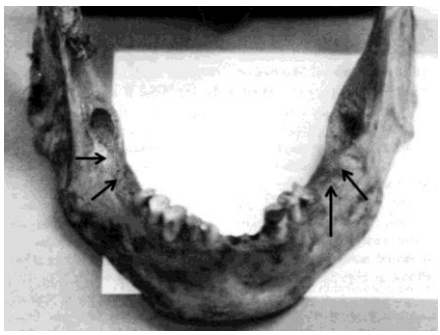


Fig 4.19. Mandibular AMTL, molars (from Hartnady and Rose, 1991:Figure 6)

(vii) Dental Wear

Dental wear is commonly used to describe the loss of enamel produced by tooth-on-tooth contact (attrition) and tooth-on food contact (abrasion), or any combination of the two that creates wear facets on the occlusal surfaces of opposing teeth or at contact

points between teeth (Kaifu et al., 2003; Pickles, 2006:86; Shellis and Addy, 2014). Dental attrition can be caused by natural mastication or abnormal use of the teeth, but it is affected by occlusion of the opposing teeth and the underlying quality of the tooth structures (Ortner, 2003:604). Severe attrition may destroy the enamel, exposing the underlying dentine and threatening to expose the pulp cavity (Figure 4.20), with resulting infection of the pulp and supporting alveolar bone (Arnold et al., 2007; Shellis and Addy, 2014). Dental attrition is frequently reported in many archaeological studies (Ortner, 2003:604), and the extent of wear has been used as a method for estimating the age of skeletons (Hillson, 1996), explained in Chapter 6.

Fig 4.20. Dental attrition with exposure of secondary dentine (from Ortner, 2003:Figure 23-34)

The presence and extent of dental wear is correlated with different factors such as age, sex, status of the individual, food abrasiveness and texture and the amount of fibrous food consumed, the degree of food processing, and non-dietary use of the teeth for preparing food or in the manufacture of artifacts (Hinton, 1981, 1982; Richards, 1984; Larsen, 1987; Lalueza Fox et al., 1996; Chattah and Smith, 2006; Hillson, 2008b:308; Hubbe et al., 2012). Clinical research also provides important evidence that excessive consumption of acidic foods may also cause tooth wear (Moynihan and Petersen, 2004; Pickles, 2006:101).

Changes in the pattern of dental wear have been used in many bioarchaeological studies for exploring dietary diversity and subsistence pattern. For example, Smith (1984) found systematic differences between hunter-gatherer and agricultural populations; agriculturalists had a characteristic form of wear that was obliquely angled over their entire molar dentition, while hunter-gatherer tended to exhibit more horizontal wear. Furthermore, Eshed and colleagues (2006) found the same differences in tooth wear between Natufian hunter-gatherers (10,500–8300 B.C.) and Neolithic populations (8300–5500 B.C.) from the southern Levant. It has been emphasized that these differences in wear are strongly related to diversities in subsistence, coarser diets, food

preparation methods, and mastication (Molnar, 1972; Smith, 1984; Larsen 1987; Hillson, 2002:292; Hillson, 2008b:307).

Tougher diets and ones that incorporate significant amounts of stone-ground abrasive particles can lead to accelerated rates of tooth wear than softer foods (Teaford and Lytle, 1996) hence with the development of ceramic cooking vessels and the consumption of a softer diet wear frequencies decline noticeably (Molleson et al., 1993; Sciulli, 1997).

4.1.3. Trauma

Trauma is the most commonly observed pathological condition in human skeletal remains (Ortner, 2003:119). It refers to an injury that affects soft tissue, bone or both (Roberts, 2000:337), and is caused by an extrinsic force to the body. Trauma can be accidental (most fractures and dislocations) or intentional (interpersonal violence) (Lovell, 1997, 2008:341; Judd, 2004), affecting the skeleton in four ways: a partial or complete break in the bone (fractures), displacement or dislocation of a bone, disruption in nerve and/or blood supply, and artificially induced abnormal shape or contour of bone (Ortner, 2003:119). Trauma is usually recorded in archaeological skeletal samples and can provide useful evidence for assessing human behaviour, including past lifestyle, work patterns, accidents, violence and warfare in a wide variety of circumstances (Merbs, 1989; Walker, 1997; Lovell, 2008:341). Any traumatic conditions to the bone produced by sword, blade weapon, piercing injuries from spear, arrow, or surgical activity like trepanation is considered to be a fracture (Ortner, 2003:120). Fractures can be classified in many types such as simple, compound, oblique, spiral, transverse, comminuted, compression, impacted, avulsion and greenstick (Roberts, 2000:339, Roberts and Manchester, 2005:89). In archaeological samples fractures observed are almost always well-healed. However, the pattern of trauma must be considered, as there might be one or more individuals among skeletal samples with a characteristic fracture pattern that can be evidence of "violent" trauma (Boylston, 2000:357). This research observed the distribution patterns of cranial trauma and interpersonal violence at *Tepe Hissar*, explained in the following sections:

(i) Weapon-Related Trauma

Analysis of weapon-related trauma, for example, blade wounds, cut marks, projectile injuries, and scalping (also see below), can be a direct source of evidence for

indicating conflict, interpersonal violence and, in general, population interaction in past societies (Larsen, 1997:119; Walker, 2001; Boylston, 2000:357; Murphy, 2003:69; Ortner, 2003:137; Novak, 2007). As Walker (2001:573) states: 'Bioarchaeological research shows that throughout the history of our species, interpersonal violence, especially among men, has been prevalent. Cannibalism seems to have been widespread and mass killings, homicides, and assault injuries are also well documented in both the Old and New Worlds.'. Patterns of violence seen in skeletal remains will vary according to socio-cultural context, time period and the type of weapons used; 'humans are able to use their superior hands and brains to create their own trauma-producing instruments, ranging from crude crushing and cutting weapons to the sophisticated ultra-destructive weaponry of modern warfare.' (Merbs, 1989:161). Bioarchaeologists have explored the pattern and causes of violence related injuries in past societies, e.g., interpersonal/group conflict with evidence of lethal trauma, unhealed injuries and mutilation (Milner et al., 1991), patterns of cranial fractures (Wilkinson, 1997), depressed cranial fractures and projectile injuries as a result of stress on resources and climatic conditions among hunter-gatherer societies (Lambert, 1997), interpersonal violence as a socio-cultural problem as seen in cranial trauma and cut marks (Walker, 1997; Frayer, 1997), and warfare/intergroup violence/massacre as seen in cut marks and fractures (Walker, 1989; Jurmain, 1991; Ferguson, 1997; Smith, 1997; Novak, 2007; Arkush and Tung, 2103). For example, Martin (1997) studied the pattern of trauma in skeletons from the La Plata River Valley and Black Mesa in Kayenta area (1000-1300 A.D). She found that environment, culture, difficulty in accessing resources, disease and mortality could have caused violence among those societies. Women were more affected than men cranially (60%:23.1% females: males) and postcranially (50%:20%).

Ante-, peri-, and post-mortem injuries

In general, skeletal trauma is classified into three distinct categories (Mays, 1998:167; Sauer, 1998:322-324; Novak, 2007). Ante-mortem traumas refer to those that occurred earlier in the individual life. In skeletal samples this kind of trauma can be recognized by signs of healing (smooth remodelled bone). Peri-mortem trauma usually occurs at or near the time of death, as indicated by a lack of healing (see below). Post-mortem traumas are clearly distinguishable with a lighter fracture margin compared to the bone surface (Mays, 1998:165; Novak, 2007:91). Injuries that occurred at the time of the death are more likely to produce an oblique fracture pattern (Boylston, 2000:359).

Accidental versus interpersonal violent injuries

Causes of postcranial trauma can be difficult to interpret because interpersonal conflicts produce a wide range of fractures, as do sport and accident related injuries (Ferguson, 1997:323). Grauer and Roberts (1996) maintain that in violent trauma bone usually breaks in a transverse direction (direct force), but in accidental injuries bone breaks with an oblique line (indirect force). However, in general, the cranium exhibits a higher frequency of peri-mortem trauma compared to the rest of the body and seems therefore more applicable for inferring interpersonal violence (Walker, 1989,1997; Milner et al., 1991; Ferguson, 1997:323; Lambert, 1997; Lovell, 1997; Novak, 2007:99). It is observed that in interpersonal violence the most dramatic injuries are to the skull and neck, which can result in injury to the brain, due to increased intra-cranial pressure from bleeding (Roberts and Manchester, 2005:108). For example, Novak (2007:91) studied human skeletal remains from a mass grave at Towton, North Yorkshire, England (1461 A.D). She reported that 113 wounds were identified on skulls while just 43 were exhibited in the postcranial skeleton, thus the head was the primary target for attack. Judd (2004) also in her study on 223 adult skeletons from the city of Kerma (1750–1550 B.C) in Egypt recorded that, among 156 observed injuries, the skull (particularly frontal and parietal bones) was the most frequently (11.2%) injured part of the skeleton, compared with long bones at 2.4% frequency. She also reported that males experienced more skull fractures than females. In the past most head injuries were probably sustained as a result of conflict using weapons (Lambert, 1997:83). Many cranial injuries occur on the left side because right-handed combatants took part in face to face and hand to hand combat (Boylston, 2000:361; Roberts and Manchester, 2005:109).

Weapon related skeletal trauma

Different weapons, the severity of the force used, the bone affected, whether the person was fighting on foot, or on horseback, and the form of protective clothing worn, all can produce different distinct types of injury, and distribution patterns that can be helpful in interpreting these events (Merbs, 1989:174; Lovell, 1997; Berryman and Symes, 1998:334; Boylston, 2000:359; Novak, 2007:91; Arbour, 2008:152). For example, swords, daggers, clubs, spears, or battle-axes produce different signs on bone. However, it is very difficult to match some injuries with a particular weapon (Boylston, 2000:359; Novak, 2007:91). Brothwell (1981) divided weapon injuries into four

categories: “gross crushing” (caused by large blunt weapons such as stones or clubs), “less extensive fracturing” (smaller clubs or maces), “piercing” (daggers, spears or arrows), and “cutting” (caused by sharp blades, such as swords and axes). Boylston (2000:359, 2004) also subdivided weapon injuries into three main categories:

(i) “Sharp” force injuries are usually produced by objects such as swords and daggers and can be easily recognized on a skeleton. Blade injuries tend to be linear, with a well-defined clean edge, and have a flat, smooth, polished cut surface, often with parallel scratch marks on the bone surface (Mays, 1998:167; Novak, 2007:91).). Sharp weapons can also produce stab wounds, which are deeper with a polished margin, but the cut marks tend to be superficial and wider rather than deep, with burnished and parallel edges.

(ii) “Blunt” force injuries are produced by blunt instruments or during falls. Cranial injuries in this category are seen as a result of the skull vault curve flattening, and the force being distributed over a large area. They are easily identified by the presence of linear radiating or concentric fractures. If the force is great it may produce a detailed delineation of the weapon margin. The area around the impact bends outwards and the centre is depressed inwards (Brothwell, 1981:119; Lovell, 1997, 2008:351; Mays, 1998:168; Boylston, 2000:363; Roberts and Manchester, 2005:109; Novak, 2007:91). King (1994- cited by Boylston, 2000:363) also produced a classification of blunt force trauma including expressed (when the broken bone projects outside the perimeter of the skull), depressed (the bone is pushed below the endocranial surface), diastatic (separation of cranial bones at sutures) and gutter fractures. The nature of a fracture in blunt force trauma may be a depressed fracture, a crack or a splinter, which is different in nature to fractures in sharp force trauma (Walker, 1989; Milner et al., 1991). Blunt instruments such as wooden clubs or stone celts are found in archaeological contexts, can be implicated as causes for blunt instrument related trauma in prehistoric contexts (Walker, 1989; Milner et al., 1991).

(iii) “Projectile” trauma is usually characterized by the velocity at which the weapon contacts the body. These injuries are produced by sharp weapons such as those made of stone, bone, metal, and wood, and by bullets, arrows, or spears which penetrate bone (Lambert, 1997:90; Boylston, 2000:363). The wound produced is small and circular, and has distinct entrance and exit holes, indicated by bone flaking around the margin of the bones affected (Roberts and Manchester, 2005:110; Novak, 2007:91). Weapons with a

high velocity can also produce extensive fractures. The nature of this type of injury implies lethal intent (Lambert, 1997:90).

(ii) Problems of Studying Trauma

When studying injuries in archaeological skeletal remains, many problems arise. For example, peri-mortem trauma can be easily confused with post-mortem damage as excavation tools can leave marks similar to blade injuries/cut mark (Milner et al., 1991; Smith, 1997; Ortner, 2003:161). In addition, if fractures occurred a short time before, or around the time of death without healing and also if polishing is absent, they may be confused with post mortem damage (Roberts and Manchester, 2005:89). The classic "butterfly" fracture of blunt force trauma to the long bone, where a butterfly shaped piece of bone becomes separated has also been seen in post-mortem changes (Ubelaker and Adams, 1995; Boylston, 2000:365). Although post-mortem alterations to bone such as excavation damage, carnivore tooth marks, weathering, cracking, and root staining may be interpreted as injuries (Smith, 1997), post-mortem damage usually produces different characteristics on dry bone from peri-mortem trauma, including a lighter colour, rougher texture and rectangular broken edge of fracture surfaces (Lambert, 1997:84; Boylston, 2000:376). An appropriate description of injuries is very important for analysing and identifying/interpreting their cause, whether accidental or violence related. Some researchers have recommended methods for recording trauma (Roberts, 1991; Buikstra and Ubelaker, 1994; Lovell, 1997; Judd, 2002) that are universally useful for all researchers (Lovell, 1997).

The next chapter reviews the principles of the carbon and nitrogen isotopes used in this study enabling paleodietary reconstruction.

Chapter 5 : BACKGROUND 3: DIET- STABLE ISOTOPIC ANALYSIS

This chapter provides a brief outline of stable isotope analysis, bone collagen and diagenesis, carbon and nitrogen isotopic signatures in foodwebs, the non-dietary factors of isotope variation, and finally the application of stable isotopic method to understand human dietary behaviour and subsistence in archaeological populations. Carbon and nitrogen isotopic signatures of bone collagen will be applied in this thesis to investigate diet and subsistence at *Tepe Hissar* which is in an archaeological area previously unexplored with stable isotopic studies.

5.1. Stable Isotopes: Definition and Terminology

Isotopes are atoms of an element with the same number of protons, but different number of neutrons (Ambrose, 1993:64). They possess almost identical chemical properties but they have different atomic masses and undertake reactions at different rates (Katzenberg, 1992:106; Thompson et al., 2008). Compared with radioactive isotopes (e.g., carbon-14/^{14}C), stable isotopes (e.g.,^{13}C/^{12}C) do not change or decay over time, and are often preserved long after death (Katzenberg, 2000:307-8). Abundances of stable isotopes values in geochemical and environmental studies are generally reported in delta (δ) units as parts per thousand (‰) or permil relative to the values of an international reference standard (van der Merwe and Vogel, 1983; Coplen, 1994; Lajtha and Michener, 1994: xii), following the general formula:

$\delta X‰ = [(R_{sample} / R_{standard}) - 1] \times 1000$ (Peterson and Fry, 1987)

In this formula "R" is the ratio of the heavy to light isotope in the sample or standard (Table 5.1). The "δ" value of the standard, by definition, is 0‰ (van der Merwe and Vogel, 1983; Katzenberg, 2000:313).

Table 5.1. Abundances of stable isotopes of C and N (Ambrose, 1993:66; Katzenberg, 2000:308)

Elements	Notation	Ratio	Standard	Isotope	Abundance (%)
Carbon	$\delta^{13}C$	$^{13}C/^{12}C$	Vienna Pee Dee belemnite (VPDB)	^{13}C	1.11
				^{12}C	98.89
Nitrogen	$\delta^{15}N$	$^{15}N/^{14}N$	Atmospheric Nitrogen (AIR)	^{15}N	0.4
				^{14}N	99.63

The values of $^{13}C/^{12}C$, and $^{15}N/^{14}N$ of a sample are compared with the values of a standard in a mass spectrometer (van der Merwe and Vogel, 1983; Katzenberg, 1992:106; Coplen, 1994). Relative to the standard, positive δ values mean enrichment of the heavier isotope components, but negative δ values mean depletion of the heavier

isotope content. These changes in isotopic contents are called fractionation (Peterson and Fry, 1987; Pate, 1994). Most biological samples have less ^{13}C than the standard, so their $\delta^{13}C$ is negative, while most $\delta^{15}N$ values are greater than zero (O'Leary, 1981; Mays, 1998:182).

5.1.1. Material Analysed in Isotopic Analysis

The most commonly used material for stable isotope studies of paleodiet is bone collagen (Sealy et al., 1995). Bone is composed of an organic matrix of the structural protein collagen, which is attached with crystal of calcium phosphate, largely in the form of hydroxyapatite. Dry bone is formed of approximately 70% inorganic and 30% organic material by weight. Almost 85-90% of the organic portion is collagen (Katzenberg, 2000:308). Bone collagen has a slow turnover rate and it decreases from 10-30%/year (at the age of 10-15 years) to 3%/year and 1.5-3%/year in females and males from 20 to 80 years respectively. The male collagen turnover rate before the age of 20 years is much greater than females, suggesting individual differences (Hedges et al., 2007). The isotopic composition of bone collagen reflects the average isotope value of dietary protein intake by an individual over a period of many years (between 10 to 30 years), and gives an average long term diet (Stenhouse and Baxter, 1979; Hedges et al. 2007). Pathological new bone formation may exhibit elevated $\delta^{15}N$ values due to protein catabolism during short term nutritional stress, injury, or disease (Katzenberg and Lovell, 1999). Therefore bones with pathological lesions may not reflect the long-term diet.

Collagen is composed of a mix of essential and nonessential amino acids. The carbon in essential amino acids comes from ingested protein in the diet, but in the nonessential amino acids may come from ingested protein, or other dietary sources (Katzenberg, 2000:309). The nitrogen in collagen must come from either ingested protein or recycled tissues in the body (Katzenberg and Lovell, 1999). So, collagen only can reconstruct the protein component of the diet and whole-diet cannot be inferred (Thompson et al., 2008). Collagen does not change after formation, and is often preserved long after death, and may survive for thousands of years (Bender et al., 1981; Armstrong et al., 1983; Nelson et al., 1986; Tuross et al., 1988; Stafford et al., 1988). Hence, it is a valuable source for stable isotope studies of dietary intake in humans and animals, and for climatic, and environmental reconstructions (Ambrose and DeNiro, 1989; Ambrose, 1990; Schwarcz and Schoeninger, 1991). The second source of carbon

in bones and teeth is in the mineral portion which is composed of hydroxyapatite (Katzenberg, 2000:307-308). Carbonate in bone is formed from dissolved bicarbonate in the blood and comes from dietary carbohydrate, lipid, and protein (Katzenberg, 2000:309). Carbonate in bone reflects a long term average of the diet (Balasse and Ambrose, 2005).

(i) Collagen Quality Indicators

For accurate dietary reconstruction, a purified tissue with well preserved collagen is required. Archaeological materials are more subject to low collagen concentration, chemical weathering, and post-mortem contamination by organic substances with the isotopic or/and elemental composition similar to the amino acids in collagen; all may affect carbon and nitrogen isotope ratios and lead to uncertain dietary interpretation (Ambrose, 1990, 1993:72). Chemical deterioration in bone with water in the burial environment and microbial attack expose the collagen to accelerate biological degradation (Collins et al., 2002; Hedges and Millard, 1995).

Several standard indicators have been proposed for detecting the quality of bone collagen preservations in archaeological samples. These include the percentage of collagen concentration of sample, atomic C:N ratios, and the carbon and nitrogen content of collagen (Ambrose, 1990; Lee-Thorp and Sealy, 2008).

(a) Collagen concentration

Collagen concentration (weight % gelatin in whole dry bone) is approximately 20-22% in modern fresh bone, but, it drops continually during burial, depending on climatic conditions and soil PH (Ambrose, 1993:72; van Klinken, 1999). When this value drops to less than 1% of the initial bone mass it should not be considered as reliable for analysis (Ambrose, 1990, 1993:75; Schwarcz and Schoeninger, 1991).

(b) Atomic C:N ratios

The atomic carbon and nitrogen (C:N) ratios of collagen, has proved to be a reliable indicator of digenetic changes and contamination; and has acceptable range from 2.9 to 3.6 (Schoeninger et al., 1989; Ambrose, 1993:74). Other studies accept range between 2.6 to 3.4 (DeNiro, 1985), and 3·1–3·5 for a well preserved collagen (van Klinken, 1999). When the ratio falls outside this range it reflects contamination or diagenesis, so such data should be rejected as non-collagenous and should not be used

(Tieszen and Fagre, 1993:122). The atomic C:N ratio often falls outside the suggested range when collagen yield falls below 1% (Dobberstein et al., 2009).

(c) Carbon and nitrogen concentrations in collagen

The concentration of carbon and nitrogen in collagen is suggested as being the most reliable indicator of collagen preservation (Ambrose, 1990). The percentage carbon and nitrogen content of bone collagen for modern animals is estimated at about 15.3- 47% and 5.5-17.3% by weight respectively (Ambrose, 1990). Other study (van Klinken, 1999) estimates carbon and nitrogen concentration about 35% and 11%-16% respectively for intact bone collagen, suggesting good collagen will have values comparable to these ranges, but a drop to under these ranges means a badly preserved bone. Samples with lower collagen exhibit lower %C, suggesting collagen breakdown (van Klinken, 1999). For the current study samples lying outside the range 2.9 to 3.6 for atomic C:N ratios or carbon and nitrogen concentrations of 35-50% and 11-16% were not included in interpretation.

5.2. Foodwebs: Carbon and Nitrogen Isotopes Compositions

Over the last forty years, stable isotope analysis of bone collagen of archaeological human and animal bones has become a well established technique in bioarchaeology for reconstruction of dietary sources and overall interpretation of lifestyle of past human populations (Ambrose and DeNiro, 1986a; Sealy et al., 1995; Richards and Hedges, 1999; Lillie and Richards, 2000; Richards et al., 2003; Keenleyside et al., 2009; Alexander et al., 2014). The use of carbon and nitrogen isotopes for dietary reconstruction is based on the assumption that "you are what you eat" (Ambrose and Norr, 1993). In fact, the carbon and nitrogen consumed during life are transferred to body tissues of consumers (humans/animals) including their bone collagen, teeth, hair, fingernails, skin, muscle and fat, allowing broad reconstructions of past dietary habits and subsistence as well as paleoenvironmental conditions (Bender et al., 1981; van der Merwe and Vogel, 1983; Tieszen et al., 1983; Krueger and Sullivan, 1984; van der Merwe et al., 1988; Schwarcz, 1991; Ambrose, 1993:71, 2000; Pate, 1994; O'Connell and Hedges, 1999; O'Connell et al., 2001; Thompson et al., 2008; Hedges et al., 2008; Alexander et al., 2014). Marine, freshwater, and terrestrial dietary proteins leave different isotopic "signatures" in human bone collagen (Schoeninger et al., 1983). Therefore, carbon and nitrogen isotopic signatures can be used to determine

the position of individuals in the food chain (herbivores or carnivores), differentiate between aquatic and terrestrial resources consumption among prehistoric humans, different photosynthetic categories (the types of plants in the food chain), and different climatic and environmental zones (DeNiro and Epstein, 1978, 1981; Chisholm et al., 1982; Schoeninger and DeNiro, 1984; Krueger and Sullivan, 1984; Sealy and van der Merwe, 1985; DeNiro, 1987; Peterson and Fry, 1987; Ambrose, 1991; Richards and Hedges, 1999; Hedges and Reynard, 2007). However, isotopic techniques cannot distinguish between particular dietary items, so interpretation is limited to distinctions of general food groups (Keegan, 1989:233; Pate, 1994). Stable isotopes are susceptible to non-dietary components (introduced in the following sections) which may influence the carbon and nitrogen ratios and make interpretation more complicated.

5.2.1. Carbon Isotope Values in Nature

Carbon in the environment, cycles through interactions of CO_2 between the atmosphere and both terrestrial ecosystems and the surface ocean (Peterson and Fry, 1987). The $\delta^{13}C$ value for atmospheric CO_2 is about -7 to -8‰ (van der Merwe and Vogel, 1983) but would have been about -5 to -6‰ in prehistoric times due to the lack of the fossil fuel carbon contribution (Schoeninger and Moore, 1992). In both terrestrial and aquatic ecosystems, carbon in terrestrial environments derives from the photosynthetic mechanism which converts atmospheric CO_2 to organic plant material with isotopic fractionation (Figure 5.1) (O'Leary, 1981:553; 1988).

(i) Carbon Isotopes in Terrestrial Foodwebs (C_3, C_4 and CAM)

Plants stand at the base of foodwebs, thus it is important to know the stable isotope values of plants to understand the position of their consumers in the food chains. The $\delta^{13}C$ value of terrestrial plants decreases relative to atmospheric CO_2 during photosynthesis (O'Leary, 1981,1988). The majority of terrestrial plants follow one of two major photosynthetic pathways, C_3 or C_4, which have characteristic different ranges of $\delta^{13}C$ (Figure 5.1). Most plants are C_3 type, including trees, wheat, barley, oats, rice, and most shrubs, vegetables, fruits, and grasses growing in temperate regions. In contrast, the C_4 plant group includes maize, sorghum, millet, some canes, and tropical grasses that are generally adapted to hot climates in arid and semi-arid regions (van der Merwe and Vogel, 1983; Sealy et al., 1995; Hoefs, 2009:178). C_3 and C_4 plants exhibit different carbon isotope ($\delta^{13}C$) values with no overlap (van der Merwe and Vogel,

1983). C_4 plants (Hatch-Slack) have significantly higher $\delta^{13}C$ values than C_3 (Calvin-Benson) plants (Pate, 1994; Sealy et al., 1995). $\delta^{13}C$ for C_4 plants has a mean of approximately -13‰ and a range between -9 and -16‰, while the mean for C_3 plants is about -26‰ with the range extending from -22 to -34‰ (Vogel and van der Merwe, 1977; van der Merwe and Vogel, 1978; Ambrose et al., 2003). These variations in carbon isotope values are delivered along the food chain to animal and human bone collagen with some further fractionation (Vogel and van der Merwe, 1977; van der Merwe and Vogel, 1978). CAM (Crassulacean acid metabolism) photosynthesis is restricted to arid-land and occurs in most, but not all, cacti and succulents, including some euphorbias and bromeliads (e.g., pineapple). CAM plant $\delta^{13}C$ values overlap the ranges of both C_3 and C_4 plants, with an average around -16.5‰ and have a range of $\delta^{13}C$ values that are not distinguished from plants using the C_4 pathway. However, they are of less importance in food webs involving humans than the other two plant types (van der Merwe and Vogel, 1978; Lajtha and Marshall, 1994).

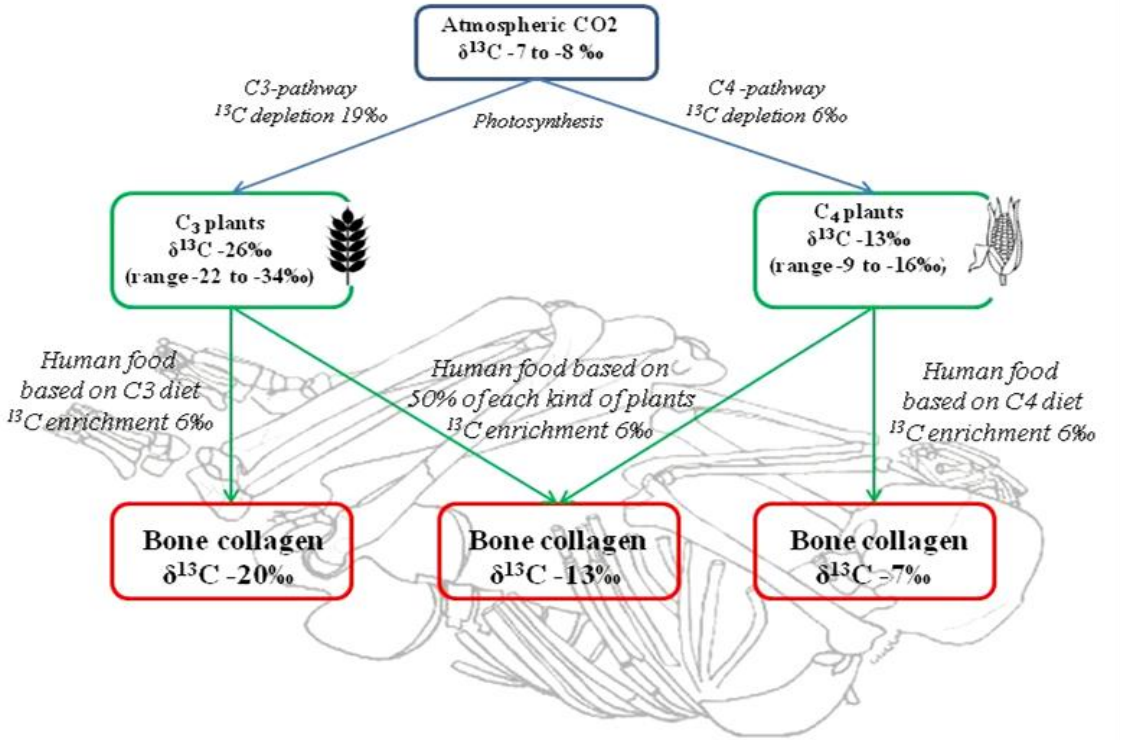


Fig 5.1. Figure showing carbon isotope fixation in the air, plants and human bone collagen, illustrating isotopic result of three hypothetical diets (redrawn from Vogel and van der Merwe, 1977:Figure.2)

Although the principal factor controlling the $\delta^{13}C$ of terrestrial plants is the photosynthesis pathway (O'Leary, 1981; Tieszen, 1991), several environmental factors (e.g., humidity, altitude, temperature, light intensity, soil type) may influence the fractionation due to changes in the fractionation due to diffusion of CO_2 relative to

enzymatic fractionation. These factors consequently influence $\delta^{13}C$ in plants and their consumers as well (Tieszen, 1991; Lajtha and Marshall, 1994). High altitudes, high humidity, and low temperature can reduce $\delta^{13}C$ values ~3-6‰ in plants and subsequently will affect the consumers (humans/animals) bone collagen in higher trophic levels as well. But in arid to semi-arid and water stressed environments the $\delta^{13}C$ values suggests enrich ~3-6‰ in plants, for example, wheat grown under low to high water levels demonstrated a $\delta^{13}C$ value enrichment of about ~6‰ (Tieszen, 1991). On the other hand, a genetic component in plants may also affect $\delta^{13}C$, since different species as well as different plant parts may show different genetic response and physiological adaptation to various environments. For instance $\delta^{13}C$ of different plant parts in grains, vegetable, and fruits is about -1.3‰ compared to wheat (-1.0‰) or corn (-4.5‰) (Ambrose, 1993:93); or in some plants seeds proteins show 3.8‰ higher than leaves and lipids exhibit 5‰ more negative than the whole plant; other example shows that among C_3 plants, woody forms may have more negative $\delta^{13}C$ than forbs in an open environment (Tieszen, 1991; Ambrose and Norr, 1993). C_4 plants however, showed no changes to the environmental factors, but genetic differences among C_4 plants species may exhibit variation in $\delta^{13}C$ (Ambrose, 1993:91). Therefore, for detailed dietary interpretation and reconstruction of past populations based on carbon isotope analysis, an adequate understanding and knowledge of the plant species at the base of the food chain, their biochemical fractionation, as well as the environmental condition, altitude, temperature, and soil types is necessary (Tieszen, 1991; Jim et al., 2004).

Tepe Hissar is located between the south-eastern slopes of the Alburz Mountains and in a semi-arid/arid temperature zone on the northeast part of Central Plateau with the annual precipitation in approximately about 92 mm. The mean annual temperature range in this region is about 14.4°C to -17°C (Meder, 1989). In the north, limited to the slopes of Alburz chains, there was Juniper forest (*Juniperus polycarpos*), shrubs and some trees including, pistachio, almond, berberis, cotoneaster as well as the hawthorn, maple, and many others (Bobek, 1968:287). These plants are resistant to cold and the ground is covered with complete steppe complex (*tragacanthic or herbaceous*). In narrow valleys near *Tepe Hissar* there are other types of trees for example, walnut, wild fruit-trees, pomegranate, ash, poplar, willow, tamarisk, which both animals and settlers humans may have had access to as a dietary resources. However, in the adjacent Central Plateau, the vegetation decrease and turns to steppe complex (*Artemesia, Artemesia*

Herab-albe) or even true desert formations at lower elevations throughout the interior plateau (ibid:287-8).

Archaeobotanical studies demonstrated that most plants cultivated and consumed during mid Hissar II to late Hissar III (3400-1900 B.C.) belonged to different species of wheat (*Triticum monococcum, T. dicoccum, T. aestivum s.I., Triticum sp*.), barley (*Hordeum distichum, H. vulgare var. nudum*) (Costantini and Dyson, 1990), with little evidence of legumes (e.g., peas, lentil seeds). All these, are C_3 plants (van der Merwe and Vogel, 1983). Thus *Tepe Hissar* residents had access to C_3 plants in their diet at that time. There is also evidence of fruits (*Vitis* and *Olea*) that are typical plants of Mediterranean agriculture, but the samples from *Tepe Hissar* were suggested to be wild species or not completely cultivated ones (Costantini and Dyson, 1990). There is no archaeobotanical report from Hissar I, but based on geo-ecological studies, Meder (1989:11) indicates high groundwater/moister conditions and plants remains such as *Typha* and *Phragmites* from the early occupation (about 4500 B.C.).

Unfortunately, there are no stable isotope measurements available for botanical samples from the site. However, Bocherens and colleagues (2000) studied the archaeological wild and domestic herbivore collagen from three prehistoric settlement mounds similar to Tepe Hissar (Tepe Zagheh, Qabrestan, and Sagzabad (samples dates 4960-863 B.C.)) in the other semi-arid zone in the Central Iranian Plateau, the Qazvin Plain and found evidence for both C3 and C4 plants. The $\delta^{13}C$ values of animal bone collagen from Tepe Zagheh (-19.6 to -16.6‰), Tepe Qabrestan (-19.7 to -16.3‰), Tepe Sagzabad (-20.5 to -15.5‰) showed the consumption of C_3 plants and significant amount of C_4 plants in some herbivores. The evidence of C_4 plants in the diet and increase in $\delta^{13}C$ accompanied by increase in $\delta^{15}N$ in some herbivores suggests arid and halophytic environments for these regions during that time. Enamel carbonate demonstrated $\delta^{13}C$ ranging from -11.3 to -4.5‰, suggesting consumption of a significant proportion of C_4 plants by animals during sixth to the first millennium B.C. in the Qazvin Plain (Bocherens et al., 2001). Modern plants samples from this area showed $\delta^{13}C$ between -28.3 to -12.6‰ (Bocherens et al., 2000) a plausible indicator of C_3 and C_4 plants in this region of the Central Plateau.

(ii) Carbon Isotopes in Aquatic Foodwebs

Although 'most terrestrial plants which have a relatively narrow range of $\delta^{13}C$ signatures are dependent primarily on their photosynthetic fractionation, e.g, C_3 vs. C_4,

aquatic plants produce a broad and potentially continuous range of signatures because of the interplay of physical as well as biological factors.' (Hecky and Hesslein, 1995:634). In marine environments carbon is absorbed from dissolved biocarbonate, with $\delta^{13}C$ values ~0‰ and about 8‰ more positive than atmospheric CO_2 (Hoefs, 2009). However, in freshwater (lake and river) environments the $\delta^{13}C$ values are highly variable (Katzenberg, 2000), depending on the source of dissolved carbon in the water, namely bicarbonate and carbonate from rock weathering, mineral springs, atmospheric CO_2, respired organic matter from plants and animals that have decayed in the water, phytoplankton and algae, as well as the pH and the temperature of the water (Peterson and Fry, 1987; Katzenberg and Weber, 1999). The $\delta^{13}C$ of plants growing in shallower water (with carbon derived from terrestrial detritus or attached algae) tend to be more positive than plants growing in deeper water (derived from pelagic plankton) and this change affects the animals living in different depths of the lake as well (see below) (France, 1995a; Katzenberg and Weber, 1999; Post, 2002). Because of difference about 7-8‰ between atmospheric CO_2 and marine bicarbonate, marine plants have more positive $\delta^{13}C$ (range -18‰ to -16‰) than freshwater ones and are more similar to C_4 plants (Pate, 1994; Sealy et al., 1995, Grupe et al., 2009). However, freshwater plants have more negative $\delta^{13}C$, similar to those for terrestrial C_3 plants (van der Merwe, 1982), but depending on their area in the water as mentioned already (in shallow or deep) (Pate, 1994), and can vary as low as -37‰ (Katzenberg and Weber, 1999; Dufour et al., 1999). $\delta^{13}C$ values in tropical lake with low dissolved inorganic ranged between -28 to -12‰ (average -20‰) (Hecky and Hesslein, 1995).

In the study area, the Damghan Plain and *Tepe Hissar* lie at the edge of desert lake basin and at the foot of alluvial fans which pour out of the Alburz Mountains into the *Kavir-e-Damghan* (a salt lake). The Damghan River is fed mainly from Jurassic karst intermittent springs (e.g., Cheshmeh Ali) and has water all around year, unites with other rivers include the *Astaneh River*, and the *Namakab Rud* (saltwater river) flowing in the Damghan region and finally pouring in the Damghan alluvial fan (Meder, 1989:8-9). It can, therefore, be assumed that the people of *Tepe Hissar* had access to freshwater resources as part of their diet. Based on geomorphological and ecological evidence from *Tepe Hissar*, Meder (1989:11) hypothesised that during 18000 to about 4500 B.C. (the beginning of Hissar I) the *Kavir-e-Damghan* had a larger expanse compared to today and offered a sweet water and "oligohaline" environmental condition. But since then and till today it has tendency toward over salting.

Although fish bones, and in general freshwater animals are less likely to survive in archaeological sites, there is some evidence of freshwater resources, e.g., fish bone (Tosi and Bulgarelli, 1989; Thornton, 2009) as well as some mollusc and ostracod at *Tepe Hissar* (Meder 1989:10), particularly from Hissar III (214 fish remains, Mashkour and Yaghmayi, 1998; Radu et al., 2008).

(iii) Carbon Isotopes in Herbivores and Carnivores Bone Collagen

The isotopic signatures of plants are passed on to consumers along the food chain (Lee-Thorp et al., 1989). Laboratory feeding experiments since the 1970s have demonstrated that the $\delta^{13}C$ of animal tissues, including bone collagen, are based on the carbon content of the diet (DeNiro and Epstein, 1978, 1981; Tieszen et al., 1983; Lee-Thorp et al., 1989). $\delta^{13}C$ increases with each trophic level (Schwarcz and Schoeninger, 1991) due to biochemical fractionation during metabolic processes (McCutchan et al., 2003). Laboratory studies showed that the enrichment ($\Delta^{13}C_{tissue\text{-}diet} = \delta^{13}C_{tissue} - \delta^{13}C_{diet}$) is approximately +1‰ to +2‰ (DeNiro and Epstein, 1978). But this depends on the type of tissue and organs (hair, bone collagen, kidney, muscle, fat, etc.) and the nature of food consumed (DeNiro and Epstein, 1978; van der Merwe and Vogel, 1983), which may stem from different biochemical compositions of the tissues, different carbon turnover rates, and assimilation of different amino acids with different $\delta^{13}C$ values (van der Merwe and Vogel, 1983; Tieszen et al., 1983; Katzenberg, 1989; Lee-Thorp et al., 1989). The tissue of most interest in bioarchaeological isotope studies is collagen (bone and dentin), due to its potential for long term preservation (Sealy et al., 1995).

(a) Carbon isotope enrichment, diet to bone collagen

Meat and collagen differ by 1.64‰ to 2.94‰ in $\delta^{13}C$ value, suggesting collagen is about 2.25‰ more positive than meat, probably due to different amino acid composition in collagen and actin myosin in muscle (Tieszen and Fagre, 1993). The enrichment between dietary isotope and bone collagen ($\Delta^{13}C_{collagen\text{-}diet)}$ in herbivores has been estimated from +3.6‰ to +5.3‰ (van der Merwe and Vogel, 1978; Schwarcz and Schoeninger, 1991; Katzenberg, 2000:314; Jim et al., 2004; Froehle et al., 2010). However, laboratory studies have found values from +1 to +6‰ (Ambrose, 1993:101). These studies showed that large mammals exhibited larger $\Delta^{13}C_{collagen\text{-}diet}$ values (+5 to +6‰) than small animals (+1 to +4.6‰) (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). This discrepancy may be due to change in the nutritional quality of food intake

(Tieszen, 1991), different metabolic rate among individuals, or error in the assumption that the diet of a browsing animal has $\delta^{13}C$ about -26‰ (van der Merwe, 1982). Nevertheless, different studies suggest that the diet-collagen fractionation is not constant and it may be under influence of food preparation technique, the amount and quality of dietary protein, and/or genetic components (Ambrose, 1993:82). Lee-Thorp and colleagues (1989) suggest that the $\Delta^{13}C_{collagen\text{-}diet}$ value for herbivores is about +5‰ relative to diet. The $\Delta^{13}C_{collagen\text{-}diet}$ values for human with terrestrial based diet estimated to be about +5.1‰ (Vogel and van der Merwe, 1977) and +6.1‰ (Chisholm et al., 1982). Although the contribution to bone collagen of carbon from dietary protein, carbohydrate and lipid is not well understood (Ambrose, 1993:82), it is demonstrated that dietary protein provides the main source of carbon rather than the whole diet (Jim et al., 2004; Ambrose and Norr, 1993), since essential amino acids derive from dietary protein (Grupe et al., 2009). Thus the isotopic signatures of carbohydrates in bone collagen may be significantly under-represented (Ambrose, 1993:82).

Herbivores with pure C_3 diets present bone collagen with $\delta^{13}C$ values of -21.4‰ to -20‰, while those with pure C_4 diets can have values of -7.4 to -7‰ (Vogel and van der Merwe, 1977; van der Merwe and Vogel, 1983). Those individuals with a mixed terrestrial diet exhibit values overlapping the ranges of both C_3 and C_4 plants (Figure 5.1) (Katzenberg, 1989). It is suggested that the $\Delta^{13}C_{collagen\text{-}diet}$ in carnivores (humans/animals) is about +4.5 to +5‰ (Figure 5.2). But comparing herbivore collagen with carnivore collagen ($\delta^{13}C_{carnivore\ collagen} - \delta^{13}C_{herbivore\ collagen}$), the difference is about +2 to +2.5‰ (Lee-Thorp et al., 1989). For example, carnivores will exhibit mean collagen about -19.0‰ compared to an average of -23.5‰ for herbivore flesh or -21.4‰ for herbivore bone collagen (Froehle et al., 2010). But other studies suggest 1‰ enrichment in the formation of bone collagen between herbivores and carnivores (Tieszen et al., 1983; Schoeninger, 1985). For example, consumption of farmed animals which consumed cereal crops with C_3 photosynthetic pathway should result in $\delta^{13}C$ around -20±1‰ (Richards et al., 2003). Omnivores such as humans exhibit intermediate $\delta^{13}C$ values (Lee-Thorp et al., 1989).

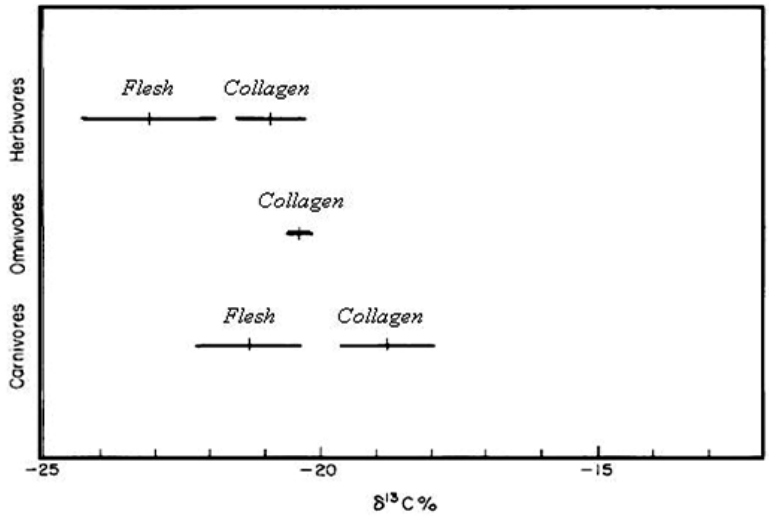


Fig 5.2. An example of the difference in $\Delta^{13}C_{\text{diet –collagen}}$ values for meat and bone collagen in herbivores, omnivores and carnivores form south-western Cape (redrawn from Lee-Thorp et al., 1989)

The $\delta^{13}C$ values of freshwater fish, crab, and shrimp is similar to terrestrial organisms with C_3 diets about -26.1‰ (for flesh) (van der Merwe et al., 1993), and ranging between -28.2‰ and -20.2‰ (bone collagen); but the marine fish collagen have $\delta^{13}C$ values similar to C_4 consuming organisms, ranging from -15.4‰ to -13.0‰ (Fuller et al., 2012). Freshwater carnivorous fish collagen averaged -18‰ (Katzenberg et al., 1995). However, it has been observed that freshwater fishes exhibit variable $\delta^{13}C$ values, due to differences in the sources of carbon in the freshwater ecosystems (see above section 5.2.1(ii)) (Katzenberg et al., 2012).

Katzenberg and Weber (1999) studied stable isotope ecology in Lake Baikal, Siberia, and reported a $\delta^{13}C$ values ranging between -14.2 to -24‰ for fish bone collagen in the lake, with fish species in the deeper part of the lake exhibiting more positive $\delta^{13}C$ than those from shallow water. On the other hand, some freshwater species, for example eels, that fish but migrate to the sea to spawn, present $\delta^{13}C$ values intermediate between purely freshwater and marine resources (-24.1‰ to -17.7‰) (Vika and Theodoropoulou, 2012; Fuller et al., 2012). Freshwater resources isotope values may change significantly with season (Vika and Theodoropoulou, 2012). The $\delta^{13}C$ value of bone collagen in an aquatic animal (e.g., fish) is ~ 3.7‰ more positive than their flesh. Individuals consuming aquatic food have $\delta^{13}C$ bone collagen ~5‰ more positive than the aquatic animals meat eaten (Katzenberg et al., 2012). But, confusion can arise when combinations of both freshwater and terrestrial foods (C_3 plants) are present, since the $\delta^{13}C$ values of consumers collagen with C_3/freshwater diet usually overlap terrestrial plants (mostly C_3 pathway) and their consumers. Therefore, it may be confusing to infer

the use of freshwater foods in individual diet directly from the carbon isotopic composition (Dufour et al., 1999).

In summary, the relative amount of potential diet sources consumed by an individual can be determined from their collagen $\delta^{13}C$ if those sources have sufficiently different $\delta^{13}C$ values, but where there is overlap in the $\delta^{13}C$ of diet sources it is difficult to determine their contributions (DeNiro and Epstein, 1978,1981; Ambrose and Norr, 1993). Therefore, $\delta^{15}N$ is helpful as it provides additional insight into the diet (Hedges and Reynard, 2007; Thompson et al., 2008).

5.2.2. Nitrogen Isotope Values in Nature

Nitrogen stable isotopes are used to distinguish the trophic levels or specific type of protein (e.g., plants, terrestrial mammals, aquatic resources) in the diet of an individual (Fuller et al., 2012). They also may indicate climatic and environmental differences within and between ecosystems and trophic levels (Ambrose et al., 1997). Figure 5.3 illustrates $\delta^{15}N$ variation in different trophic levels in terrestrial food chain. The ultimate source of nitrogen in the food chain is atmospheric nitrogen (Ambrose, 1991) with $\delta^{15}N$ of 0‰ (Mariotti, 1983). The $\delta^{15}N$ in soils is about +10‰ and dissolved nitrogen in the ocean has a $\delta^{15}N$ of about +1‰ (Pate, 1994). Manuring tends to increase the $\delta^{15}N$ values in soil and consequently in plants and herbivores, depending on intensity and frequency; therefore in this case the $\delta^{15}N$ values for human bone collagen may be mistaken as evidence of a high animal protein diet or mix plant/animal protein diet (Bogaard et al., 2007). But, high $\delta^{15}N$ values in herbivorous animals (e.g., sheep, goat) can be a direct indicator of manuring practice. Hot, arid regions and desert saline soils tend to produce high $\delta^{15}N$ values in some animal species and to a lesser degree in plants, probably due to evaporation of isotopically light ammonia from the soil leaving enriched nitrogen to be used by plants or animals, or water/ dietary stress, leading to recycling of nitrogen within the herbivore body and producing a $\delta^{15}N$ enrichment which is more pronounced with increasing stress intensity (Heaton et al., 1986; Ambrose and DeNiro, 1986a; Sealy et al., 1987; Heaton, 1987; Keegan, 1989:229; Ambrose, 1991; Schwarcz et al., 1999). Within these ecosystems, herbivore species with physiological adaptations to water conservation have higher nitrogen isotope values than water-dependent species. Cool humid forest soils tend to have higher nitrogen fixation and lower $\delta^{15}N$ values than hot, dry desert soils (Ambrose, 1991). Laboratory experiments

revealed that animal tissues were enriched in ^{15}N during constitutional nutritional stress and starvation (Hobson et al., 1993; Gaye-Siessegger et al., 2007).

It has been suggested that there is a negative correlation between rainfall and $\delta^{15}N$ values in both soils and plants, and therefore with increasing mean annual rainfall and decreasing annual temperature the $\delta^{15}N$ value decreases (Heaton et al., 1986; Schwarcz et al., 1999; Amundson et al., 2003). *Tepe Hissar* is located in a semi-arid/arid climatic zone with a mean temperature of 14.4 to -17 °C and precipitation of about 92 mm/year (see above section 5.2.1 (i) - Meder, 1989) which is probably sufficient to increase the $\delta^{15}N$ value due to the zone's aridity and possible high temperatures in the summer.

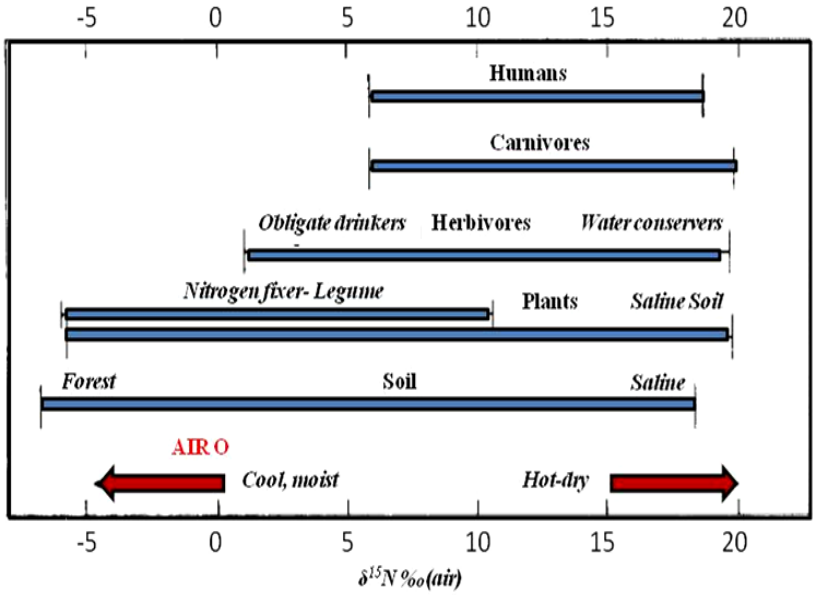


Fig 5.3. Variation in $\delta^{15}N$ values in different trophic levels of terrestrial foodwebs (redrawn from Ambrose, 1991:Figure.1)

(i) Nitrogen Isotopes in Terrestrial Foodwebs

Nitrogen is absorbed by plants from soil (nitrates, ammonia, ammonium, animal urea) and some plants taken it directly from atmospheric nitrogen (Mays, 1998:183). There are two major processes transferring atmospheric nitrogen into the biological systems (Figure 5.3), the first is nitrogen-fixing organisms, e.g., in terrestrial ecosystems the legumes (peas and beans) and in aquatic ecosystems blue and green algae. The second is bacterial mineralization, which results in plants having more enriched $\delta^{15}N$ values (DeNiro and Epstein, 1981; Peterson and Fry, 1987; Schoeninger and Moore, 1992; Pate, 1994). Terrestrial nitrogen-fixing plants have mean $\delta^{15}N$ between 0‰ and +4‰, while other plants that obtain their nitrogen from soil (both C_3 and C_4) have mean $\delta^{15}N$ of about +3‰ (DeNiro and Hastorf, 1985; Pate, 1994; Shearer and Kohl, 1986). Nevertheless, many factors (e.g., temperate environment, manuring, rainfall) (see

section 5.2.2) will cause variation in the $\delta^{15}N$ values in plants and consequently their consumers. Thus, knowledge and information on $\delta^{15}N$ of botanical samples from the area under study is very important for detailed interpretation of animal and human $\delta^{15}N$ values (Cabana and Rasmussen, 1996; Bogaard et al., 2007). There is no nitrogen isotope analysis from *Tepe Hissar* botanical samples, but the isotopic measurements of modern flora from the other arid area from the Central Iranian Plateau, the Qazvin Plain, exhibit $\delta^{15}N$ between +2.2 to 6.4‰ (n=4), and +9.9‰ for a legume (n=1), and -0.4 for a plant from oats family (n=1) (Bocherens et al., 2000; Ramaroli et al., 2010).

(ii) Nitrogen Isotopes in Aquatic Foodwebs

Dissolved nitrates in seawater are the main source of nitrogen for aquatic food chain with $\delta^{15}N$ about 1‰ (Pate, 1994). Nitrogen isotope values for aquatic resources (Figure 5.4) are up to ~8‰ more positive (based on the primary produces-phytoplankton (Grupe et al., 2009)) than the $\delta^{15}N$ values in terrestrial ones (Schoeninger et al., 1983; Schoeninger and DeNiro, 1984; Ambrose et al., 1997; Bocherens et al., 2007), providing data complementary to $\delta^{13}C$ for estimating the contribution of aquatic foods to human diets (Hu et al., 2006). There is large variability in $\delta^{15}N$ in aquatic environments due to differences in the $\delta^{15}N$ of nitrogen source, plant species (nitrogen fixer/non nitrogen fixer), and factors influencing fractionation (Cabana and Rasmussen, 1996). In addition, $\delta^{15}N$ values elevated about 5-10‰ with increasing depth in the water (Peterson and Fry, 1987). Studies suggest that the $\delta^{15}N$ signature of aquatic plants in both marine and freshwater ecosystems can vary from -2‰ to up to +6-10‰ during the year depending on their location in the water (Cabana and Rasmussen, 1996; Dufour et al., 1999; Grupe et al., 2009). However, marine organisms (both plants and fish) are about 5‰ more enriched in $\delta^{15}N$ than organisms living in freshwaters (Schoeninger and DeNiro, 1984; France, 1994, 1995b).

(iii) Nitrogen Isotopes in Herbivores and Carnivores Bone Collagen

Laboratory animal feeding experiments have shown that the $\delta^{15}N$ in animal tissues is systematically enriched relative to diet (Gaebler et al., 1966; DeNiro and Epstein, 1981), and all tissues, flesh, hair, blood, or bone collagen have similar $\delta^{15}N$ (Katzenberg et al., 2012). Studies of ancient and modern ecosystems have indicated to 3-5‰ stepwise enrichment between trophic levels in both aquatic and terrestrial ecosystems from plants to herbivores and finally to carnivores (DeNiro and Epstein, 1981; Ambrose

and DeNiro, 1986a; Sealy et al., 1987; Schwarcz, 1991; Schwarcz and Schoeninger, 1991; Post, 2002; Bocherens and Drucker, 2003; Robbins et al., 2005; Bogaard et al., 2007). Other research indicates trophic level enrichments between 1‰ and 6‰ (Sponheimer et al., 2003). However, non-dietary factors (see above) such as biochemical, environmental/climatic (e.g., arid, cool), and physiological factors (e.g., starvation, water stress), as well as possible intra individual variation and different metabolic rates in nitrogen enrichment may affect the $\Delta^{15}N_{collagen\text{-}diet}$ values, consequently affecting interpretation of source of human food (Hedges and Reynard, 2007). For example, plant $\delta^{15}N$ in the arid areas of Iran with average rainfall about 200–300 mm/year is about +4.9 to +5.3 (Ramaroli et al., 2010), which would indicate $\delta^{15}N$ in terrestrial animals about +9±1‰ if the accepted value is 3-5‰ for trophic level enrichment. However, in semi-arid to arid areas with low rainfall like the Qazvin Plain in the Central Iranian plateau with mean $\delta^{15}N$ values about +4.3‰ for modern plants, terrestrial food web produced animal bone collagen with $\delta^{15}N$ values range between 8.0-10.6‰ for the ancient site Tepe Zaghe (samples dated 4960-4560 B.C.), 8.1-12.0‰ for Tepe Qabrestan (samples dated 3782-3102 B.C.), and 8.1-11.2‰ for Tepe Sagzabad (samples dated 1294-863 B.C.), some of which are a little higher than estimated, suggesting a correlation between $\delta^{15}N$ enrichment and saline dry environments during that period (Bocherens et al., 2000), as well as possible physiological reactions of animals to environmental factors. In the arid area of south-west Turkmenistan (1300B.C. to 12A.D.), domestic herbivores exhibited $\delta^{15}N$ between +5.4 to 15.1‰ (Bocherens et al., 2006). Nonetheless, individuals with regular access to water and/or very low dietary protein may show a smaller ^{15}N enrichment compared to those from a hot dry environment with higher protein intake (Ambrose, 1993:99). Experimental isotopic analysis on the hair of pregnant women who experienced nutritional stress during pregnancy showed enrichment in ^{15}N (Fuller et al., 2004, 2005). Unfortunately, there are limitations in our knowledge and understanding of other factors (e.g., genetic, pathological, pollution, environmental, etc.) that may have affected the $\delta^{15}N$ values of ancient populations, and will influence our interpretation and the results of dietary reconstruction (Hedges and Reynard, 2007).

The main dietary protein resources for humans are plants, terrestrial mammals (meat, milk), and aquatic resources (Hedges and Reynard, 2007). For example, terrestrial herbivores exhibit $\delta^{15}N$ from +6 to +12‰ (mean +9‰) depending on the plants intake and environment, and carnivores exhibit mean $\delta^{15}N$ about +12-13‰. Omnivores like

humans exhibit intermediate values (Schoeninger et al., 1983; Dufour et al., 1999; Sealy, 2001). Higher $\delta^{15}N$ value in herbivore bone collagen may suggest consumption of non-leguminous plants, while lower $\delta^{15}N$ indicates consumption of legumes (Schoeninger and DeNiro, 1984; Katzenberg, 1992:107). In omnivores $\delta^{15}N$ is more influenced by animal protein consumed than plant protein, as the percentage of protein in animal tissues is much more (85-90%) than in plants (10-25%) (Ambrose et al., 2003). It is impossible to differentiate between dietary protein sources derived from the same animal (e.g., meat and milk), as all protein products derived from one animal have the same isotopic profile (O'Connell and Hedges, 1999; Hedges et al., 2008). Breastfeeding children will have $\delta^{15}N$ values 2-3‰ higher than their mothers, since they are in effect consuming their mother's tissues (Fuller et al., 2003).

Nitrogen isotope values for aquatic animals (e.g. fish) or humans consuming aquatic resources are typically more positive than those for terrestrial diets (Pate, 1994; Fuller et al., 2012). This is because the large number of steps in aquatic food chains results in more trophic level increases (Privat et al., 2002). For example, the $\delta^{15}N$ values bone collagen of freshwater fish is about +6.6 to +9.5‰ (Schoeninger et al., 1983) or +7.2 to +16.7‰ (Fuller et al., 2012). High $\delta^{15}N$ suggests carnivorous fish species (Grupe et al., 2009).

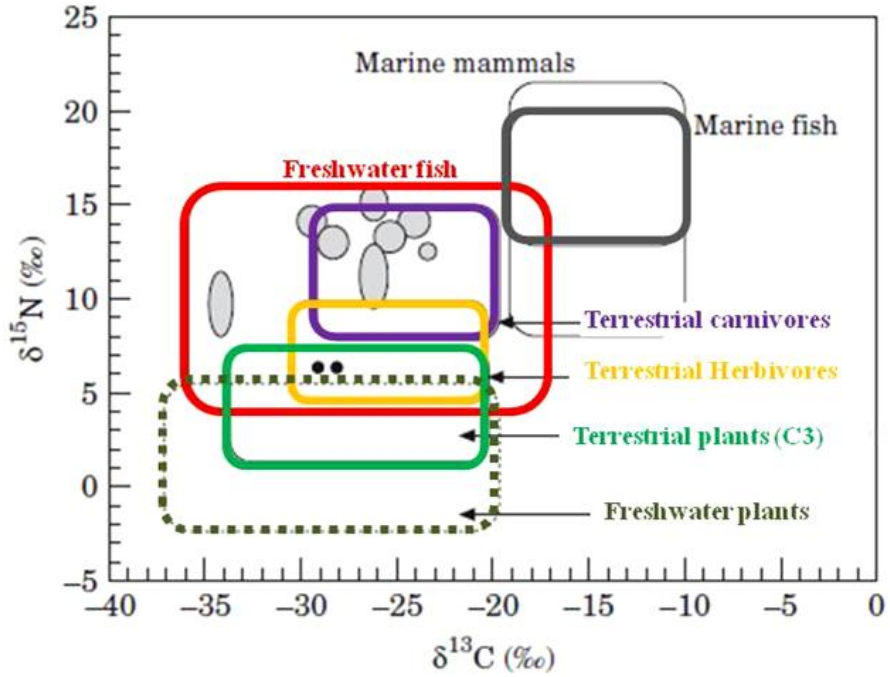


Fig 5.4. An example of $\delta^{13}C$ and $\delta^{15}N$ variations in different trophic levels (redrawn from Dufour et al., 1999:Figure.5)

In summary, nitrogen isotope dietary analysis makes it possible to determine the trophic level of an individual, and their diet. The $\delta^{15}N$ value of terrestrial herbivores is

less positive than carnivores. But this value will increase when aquatic resources such as fish are consumed, and in combination with $\delta^{13}C$ it is possible to differentiate between marine or freshwater foods. In addition to dietary reconstruction, nitrogen isotopes are used to explore palaeoenvironmental changes (Bocherens et al., 2000), ancient manuring for cultivation (Bogaard et al., 2007), nutritional stress and starvation in animals (Hobson et al., 1993; Gaye-Siessegger et al., 2007; McCue and Pollock, 2008), and past weaning practices (Katzenberg et al., 1993; Fuller et al., 2003, 2006). Nonetheless, complexities arise from different non-dietary factors which may affect $\delta^{15}N$ values in foodwebs and may make the dietary interpretation more complicated and uncertain (Katzenberg et al., 1995; Cabana and Rasmussen, 1996).

5.3. Contribution of Carbon and Nitrogen Isotopic Signatures in Paleodietary Reconstruction

The archaeological significance of applying isotopic analysis for archaeological human dietary reconstructions was recognized in 1970s. The earliest studies, employed bone collagen $\delta^{13}C$ to distinguish between C_3 and C_4 plants and to trace the introduction of maize into the diet of North Americans (Vogel and van der Merwe, 1977; van der Merwe and Vogel, 1978). Other studies demonstrated the utility of $\delta^{13}C$ to determine the proportion of marine versus terrestrial protein in archaeological human diet (Tauber, 1981; Chisholm et al., 1982). Studies using $\delta^{15}N$ developed in early 1980s. Marine and terrestrial resource use was investigated among Eskimos and northwest coast Indians. Individuals with marine food (Eskimos) exhibited more positive $\delta^{15}N$ (+17-20‰) than those who consumed terrestrial food (agriculturalists +6-12‰), but individuals with a diet based on freshwater fish showed $\delta^{15}N$ values intermediate between marine and territorial consumers (Schoeninger et al., 1983; Schoeninger and DeNiro 1984). Later Ambrose and DeNiro (1986b) studied $\delta^{13}C$ and $\delta^{15}N$ in bone collagen of historic and prehistoric African human populations to determine the differences between herbivore and carnivore trophic levels, marine and pastoralist populations and farmers in that region.Over the past few decades the use of carbon and nitrogen isotopic data from ancient human bones for dietary reconstruction has become increasingly frequent in different geographical regions in the world (Bender et al., 1981; Schwarcz et al., 1985; Schoeninger and Moore, 1992; Lee- Thorp et al., 1993; Richards and Hedges, 1999; Richards et al., 1998, 2003, 2005; Hu et al., 2006; Vika and Theodoropoulou, 2012; Valentin et al., 2010; Fuller et al., 2012a; Alexander et al., 2014).

Unfortunately, very little isotopic study of human dietary reconstruction has been published on archaeological human populations from Iran particularly from the Chalcolithic and Bronze Age Central Iranian Plateau and northern Iran. Bocherens and colleagues (2000) utilised $\delta^{13}C$ and $\delta^{15}N$ to reconstruct palaeoenvironmental changes during the sixth to the first millennium B.C. in the Qazvin Plain. They studied animal bone and there were just four human bones available for isotopic studies. The isotopic data from human remains from Tepe Zagheh (sixth millennium B.C.) produced bone collagen with mean $\delta^{13}C$ bout -19‰ and $\delta^{15}N$ ranging between 11 to 13.6‰, suggesting consumption of animal meat and/or dairy products. Later Bocherens and colleagues (2001) studied carbon and oxygen isotopic variations in animal tooth enamel to reconstruct archaeological herd management in the arid area of Iran. Ramaroli and colleagues (2010) used carbon and nitrogen isotope analysis of the Chehr Abad "Salt Men" (4^{th} century B.C.-4^{th} century A.D.) from the salt mine in Zanjan province, Iran. They attempted to identify the geographical origins of the men (n=5) by comparing the carbon and nitrogen values of these people with other isotopic information, mostly from domestic and wild animals from other archaeological sites.

5.4. Limitations

At present it may not be promising to calculate absolute diet isotopic values based on measured isotope ratios in collagen (Schoeninger and Moore, 1992). The method is not fully able to provide the level of details or reliable percentage for different protein sources in the dietary menu of an individual. It is not easy to estimate, for example, accurate percentages for fish, terrestrial meat, and plants consumed by an individual (O'Connell and Hedges, 1999; Hedges et al., 2008). In the absence of archaeozoological samples, however, it is not possible to interpret whether the proteins eaten come from domestic animals or wild terrestrial animals, or egg or dairy and so on. Similarly, it is not easy to interpret if an increase in $\delta^{15}N$ was due to dietary protein or environment, manuring or even diseases or nutritional stresses. This information, however, is particularly important when studying diet of prehistoric populations. Nevertheless, in this respect Schoeninger and Moore (1992:248) state that, 'The analysis of bone stable isotope composition does not provide a clear window to the past but, rather, permits one to look "through a glass darkly." Shading is produced by bone turnover rates, metabolic variation, and diet complexity, among other sources of biological variability.'

The following chapter describes the skeletal materials and the analytical methods used.

Chapter 6 : MATERIALS AND METHODS

This chapter explains the materials and methods employed in this research. The following methods were selected to test the current research hypotheses and questions.

6.1. Materials

(i) The Tepe Hissar collection

The skeletal collection from *Tepe Hissar* is curated at the University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia, USA (UPM). This collection after Shahr-i Sokhta (curated at the site in Iran), is one of the largest human skeletal collections available from Iran. From the 1637 skeletons uncovered during Schmidt's excavations (1933-1937), 397 skeletons have been housed at UPM since that time, but the rest of the skeletal remains are in an unknown location in Iran. The skeletal remains at UPM are dated from the Chalcolithic to the Bronze Age (late 5^{th}-2^{nd} millennium B.C- Hissar I, II and III), from an "unknown" period (n=9) and the Islamic period (Middle period- Roustaei, 2010) (n=5). The focus of this research was the human skeletal remains dating to the early Chalcolithic and Bronze Age, so a total of 368 adults, of which 28 were from Hissar I, 53 from Hissar II, and 287 from Hissar III have been examined in the current research.

(ii) Past skeletal studies of Tepe Hissar: the UPM collection

The first study of the *Tepe Hissar* skeletal remains was done by Wilton Krogman (1940a and b), focusing on "racial" types of the recovered crania. Krogman studied 216 individuals. He states that the basic cranial type at *Tepe Hissar* was two types of long heads: Mediterranean (smaller smooth skull) and Nordic (larger rugged skull), the former type to find in early Iran and the Nordic belong to Steppe Caspian area. However, by Hissar III other ethnic group such as Negroid, Armenoid, and Mongoloid were but tangential to the main orbit of ethnic domestic (ibid,1940a). He (1940c) also gave a basic report and a brief overview on the skeletal and dental pathologies. Later, Mario Cappieri (1973) used the metrical data for comparison of variation between South Asian populations. He stated that no "cross-breeding" occurred at *Tepe Hissar* and the settlement had its own origin, evolution and continued occupation by the same homogeneous genotype. Nowell (1978) examined the "Miles" system of ageing based upon the rate of molar wear for the *Tepe Hissar* dental sample. He studied 479 human skeletal remains but stated that these skeletons do not represent the prehistoric

population of this site and could not be used to generate meaningful demographic statistic (ibid, 1989). However, Rathbun (1989) found that the males in this population showed close biological affinities with skeletal samples from India and Turkmenia, and females were more similar to those from Anatolia, Hassanlu, and Kish (Iraq). Nevertheless, these studies just provide some basic information about the populations of *Tepe Hissar*.

In more recent years, Hemphill has led a number of craniometric studies (Hemphill et al., 1997; Hemphill, 1998, 1999a-b, 2008; Hemphill and Mallory, 2004) for comparative analyses of relative variation among the Oxus Civilization and Bronze Age Iran and the Indus-valley populations. However, in these studies, he treated Bronze Age *Tepe Hissar* mainly as part of a much larger sample used for his research. He also compared dental non-metric traits of 136 individuals from *Tepe Hissar* (Hissar III) with 22 prehistoric and historic sites from Central-Asia, the Indus-valley and Iran to investigate gene flow between these regions (Hemphill, 2011). Afshar (2006) compared biological affinity between people from *Tepe Hissar* (Hissar II and III) and the Bronze and Iron Age south Caspian Sea region (Shah Tepe, Gohar Tepe, and Dailaman- see Chapter 3) with the contemporaneous North Bactrian populations. Barton and Hemphill (2011) employed a craniometric study of the Bronze Age population from Central-Asia and Iran (*Tepe Hissar*, Shahr-i-Sokhta and Hasanlu IV) to investigate the biological relationship between these areas, and O'Neill and Hemphill (2011) assessed the pattern of permanent tooth size to investigate the biological affinities between the Bronze Age populations from *Tepe Hissar*, Hasanlu IV and samples from Central-Asia and the Indus-valley. Nonetheless, the origin of the *Tepe Hissar* population for each period, their biological relationship and/or direction of gene flow into this site is still not well understood.

All of these previous studies on the human skeletal remains from *Tepe Hissar* offer a significant contribution to our knowledge of the biological history of the population. However, there is currently no comprehensive publication available on biological relationship within and between periods, general health, metabolic diseases, isotopic analyses of diet, or interpersonal violence. The skeletal series from *Tepe Hissar* is an incredibly rich collection which contains human skeletal remains from the early to the late occupation of this site and potentially provides a key test of the popular and conventional image of the Chalcolithic and Bronze Age there, but also open a new window on evidence that is central to gaining an understanding of the lives and social

environment of the ancient populations from the Central Iranian Plateau during that time; it has not been utilized to its full potential.

The aim of this study was to test hypotheses outlined in Chapter 1 regarding population influxes into the Central Iranian Plateau as reflected in socio-cultural-economic changes at *Tepe Hissar* during the Chalcolithic and Bronze Ages, and to understand if the changes that occurred at *Tepe Hissar* over time impacted on subsistence economy, diet, and general health of the population, and also resulted in a rise in tension and interpersonal violence. In order to address the aim of this study, test the hypotheses, and answer the questions set out in Chapter 1, the following methods are utilized. It is anticipated that the results of this study will expand our knowledge of one of the ancient Central Iranian Plateau populations during the Chalcolithic and Bronze Age, providing a foundation for future bioarchaeological research in Iran.

6.2. Methods

6.2.1. Skeletal Recording Form

Since many archaeological human skeletal remains are incomplete, to maximize the amount of information retrieved and enable comparative studies, a standard recording form is essential in bioarchaeological research (Buikstra and Ubelaker, 1994:5). In this respect a recording form was developed for the present research (Appendix 1). This form was designed based on a modified version of the guidelines detailed in Buikstra and Ubelaker (1994) and Brickley and McKinley (2004). A separate recording form was used for each individual for recording bone and tooth inventories, age-at-death, sex, metrical and non- metric data, pathological lesions and cranial trauma.

6.2.2. Preservation

The degree of skeletal and dental completeness for each skeleton was scored separately based on the estimated percentage of the skeletal and dental remains preserved for each individual. When recording skeleton completeness, factors such as post-mortem damage were considered. Diagrams of adult teeth (Buikstra and Ubelaker, 1994, attachment 14a) and the skeleton (Brickley and McKinley, 2004:58-59) for visual recording were attached to each form, and shaded based on the percentage preservation of each bone and tooth to illustrate the degree of completeness for each skeleton. All teeth and bones were described as: complete when 75% to 100% of a bone/tooth was preserved, partial with 25% to 75% of a bone/tooth preserved, and poor with less than

25% of a bone/tooth preserved. The category of absent (0%) was used when a tooth /bone was not present (Buikstra and Ubelaker, 1994).

6.2.3. Palaeodemographic Profile

A palaeodemographic profile reconstructs sex and age distributions, to study population size and growth, assess the impact of migration and fertility, and mortality rates and life expectancy; it further helps to explore the impact of stress and disease on mortality in archaeological populations (Roberts and Manchester, 2005:22-29; Chamberlain, 2000:101, 2006). In prehistoric cemeteries, it is not easy to accurately construct paleodemographic profiles from archaeological evidence due to the vagaries of archaeological excavation and the limitations of analysing skeletal remains (Wood et al., 1992; Waldron, 1994; Roberts, 2009:137). For example, the number of skeletons excavated from a site can be only a small portion of the original living population (Waldron, 1994). Females and males, non-adults, and diseased people may also have been buried in different areas of cemetery or elsewhere. These factors ultimately eliminate a certain group of society if those parts of the cemetery are not found and/or excavated (Wood et al., 1992; Roberts and Manchester, 2005:24), and affect the interpretation of population size, sex and age distribution, and mortality rates. Moreover, in many contexts sometimes it is difficult to understand if the skeletons excavated were part of the indigenous population or were possibly nomadic and/or deriving from other groups, perhaps from a different time period that temporarily resided. Other factors specific for the site location and people buried there, such as post-mortem damage, type of soil, climate, disturbances of archaeological sites with modern activities such as farming and road construction, and bone density and size (children's skeletons, particularly those of foetuses and infants, as well as older adults are more susceptible to physical damage) can affect the level of preservation of the skeletons, and ultimately the demographic profile reconstructed (Henderson, 1987:43-54). The problem of inter- and intra-observer error can also influence the morphological assessment of skeletons for age and sex (Kemkes-Grottenthaler, 2002:55).

Many methods of sexing and aging have been developed and tested on modern (19^{th} and 20^{th} century) known age and sex populations from different genetic backgrounds who had particular diets, diseases, occupations, living environments, and lifestyles (e.g., the Hamann Todd Collection at the Cleveland Museum of Natural History, Ohio, USA). However, these methods may not be, and probably are not,

appropriate for use on an archaeological skeletal populations with uncertain genetic and environmental backgrounds (Whittaker, 2000:83; Roberts and Manchester, 2005:36). Even so, Mays (2010:59) states 'At present, the lack of a wholly satisfactory technique for estimating age-at-death in adult skeletons from archaeological sites is one of the most thorny problems facing human osteoarchaeology.'. In this respect, the current study utilized a combination of these methods with caution, as there are no sexing and ageing methods developed for documented Iranian populations.

(i) Sex-Estimation

(a) Introduction

The estimation of sex is one of the essential requirements for studying human skeletal remains and past population demography (Chamberlain, 2006; Mays, 2010:88). Sex-estimation in adult skeletons relies primarily on visual differences in skeletal morphology between males and females, and on measurements taken from certain bones (Bass, 1995; Mays and Cox, 2000:118; Roberts and Manchester, 2005:32). However, it is not possible to estimate sex in non-adult skeletons, since the morphological changes in skeletons which define sex differences are not expressed until puberty (Scheuer and Black, 2000a:15; Robert and Manchester, 2005:31). This limitation has a direct influence on demographic profiles because it is not possible to explore differential non-adult mortality between the sexes. When sexing adults, it is also important to note that factors such as genetic disorders, disease, occupation and diet can influence the morphology of the skull and pelvis (Mays and Cox, 2000:125).

The expression of sex related traits may also vary within and between individuals and populations (St. Hoyme and Iscan, 1989:64; Roberts and Manchester, 2005), and there might be considerable overlap in the range of male and female trait expression in both sexes, or even in one skeleton (Walrath et al., 2004). For example, in some individuals the pelvis may sometimes indicate one sex while the skull indicates another (Meindl et al., 1985a; Mays and Cox, 2000:118), and some young males may appear more feminine with small skeletons while older females may appear more robust and masculine (Walker, 1995). These issues influence the accuracy of sex-estimation in skeletons. It has been recognized that the pelvis is the most reliable area of the skeleton for sexing, and the skull is the second (Acsádi and Nemeskéri, 1970; Sutherland and Suchey, 1991; Ubelaker, 2004:53). There are methods for sex-estimation for

archaeological skeletons which use sex-specific DNA sequences, but good preservation of the bone and teeth is important for these analyses (Chamberlain, 2006:19).

The completeness of the skeletal remains is very important for an accurate and reliable sex-estimation, particularly in populations with low sexual dimorphism (Mays and Cox, 2000:118; Mays, 2010:40). Due to poor preservation of some skeletons from *Tepe Hissar*, a combination of methods of sexing was utilised, as recommended by Buikstra and Ubelaker (1994). Estimation of sex in adults was based on sexually dimorphic traits of the cranium and mandible (Acsádi and Nemeskéri, 1970; Buikstra and Ubelaker, 1994; Bass, 1995; Loth and Henneberg, 1996) and pelvis (Phenice, 1969; Acsádi and Nemeskéri, 1970; Buikstra and Ubelaker, 1994:3; Bass, 1995; Brickley, 2004). Measurements of long bones such as the femoral, humeral and radial-head diameters, the femoral-bicondylar width, clavicle length, and scapula-glenoid width were also recorded (Bass, 1995). Each skull, pelvis and measured bone was assigned to one of the following: male (M), possible male (M?), indeterminate (?), possible female (F?), and female (F). However, in order to simplify the analysis and increase the sample size for both sexes, the analysis of results considered females and possible females as female, males and possible males as male; skeletons with ambiguous traits were assigned unknown sex.

(b) Pelvic sexual dimorphism

Pelvic morphology is considered to be the most reliable indicator of biological sex, with an accuracy of between 90% and 95% (Phenice, 1969; Brothwell, 1981:62; Meindl et al., 1985a; Sutherland and Suchey, 1991; Meindl and Russell, 1998). Sexual dimorphism in the pelvis is due to functional differences, in particular childbirth in females (Saunders, 2000). In this study, 11 indicators of sex in the pelvis were recorded including the greater sciatic notch, obturator foramen (Acsádi and Nemeskéri, 1970), the pelvic inlet and outlet, acetabulum size, sub-pubic angle, sub-pubic bone length (Bass, 1995:202), the ventral arc, the sub-pubic concavity, and the medial aspect of the ischio-pubic ramus (Phenice, 1969), the preauricular-sulcus (Cox, 2000a), and the morphology of the sacrum (Bass, 1995). It is recognized that the pelvis in females is usually wider and rounder (transversely oval) than in males (Figure 6.1). The male pelvis is a high and narrow structure and more robust with well marked muscular impressions (ibid, 1995:202). The acetabulum in males is larger than in females, and the obturator foramen

is larger and oval in males (Figure 6.1), while it is smaller and more triangular in shape in female (Acsádi and Nemeskéri, 1970; Brothwell, 1981; Bass, 1995:202).

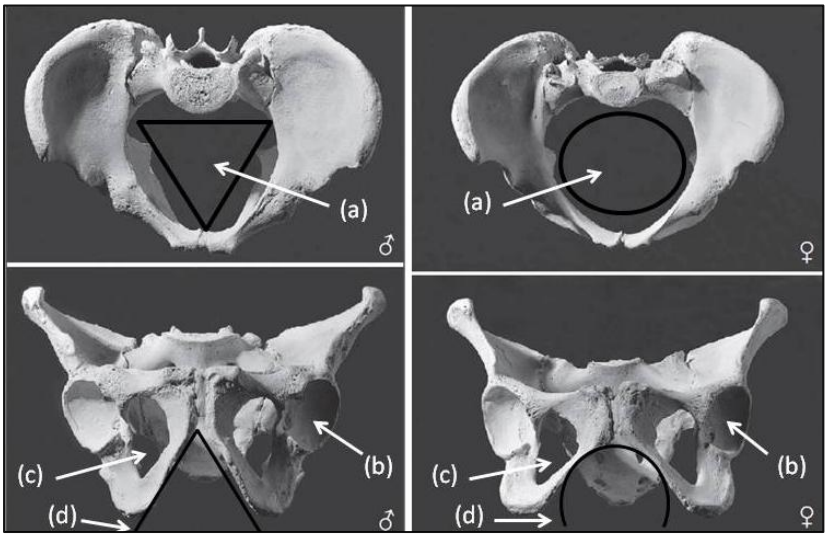


Fig 6.1. Pelvis morphological dimorphism between male (left) and female (right),(a) pelvic inlet,(b) acetabulum,(c) obturator foramen, and (d) sub-pubic angle (White and Folkens, 2005:Figures 19.13-14)

The greater sciatic notch (Figures 6.2 and 6.3) in females is relatively wider and shallower (with an angle of about 60 degrees) compared to males (with an angle of about 30 degrees- Acsádi and Nemeskéri, 1970; Ubelaker, 2004:54). However, the expression of this trait can vary between different populations with different ancestries; e.g., Walker (2005) showed that the 18th and 19th century English individuals from St. Bride's Church had a more feminine morphology than Americans of European or African ancestry. The accuracy of sex-estimation based on the width of the great sciatic notch ranges from about 79% to 89% (Durić et al., 2005). The greater sciatic notch has a tendency to be narrower in females who suffer from vitamin D deficiency (Builkstra and Ubelaker, 1994:18; Walker, 2005); there is clear relationship between the width of the sciatic notch and age-at-death, where younger adults showed a wider notch than older adults (Walker, 2005).

Fig 6.2. Sexual dimorphism of the greater sciatic notch-left pelvis (Mays, 2010:Figure 3.3)

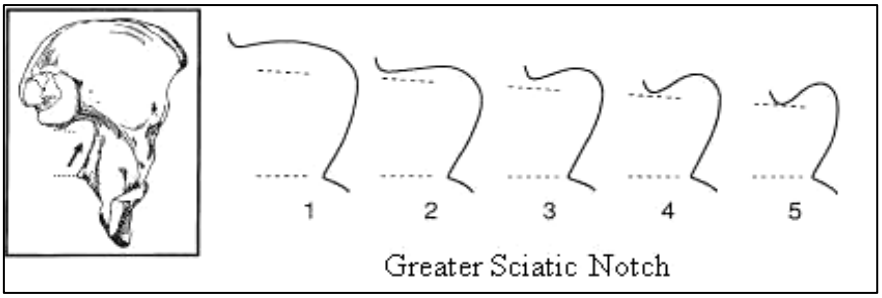


Fig 6.3. The range of expression of the greater sciatic notch from 1 (definitely female) to 5 (definitely male) (Buikstra and Ubelaker, 1994:Figure 2)

The preauricular-sulcus is a "groove" between the auricular surface and the sciatic notch. This feature appears mostly in females, but seldom in males (Cox and Scott, 1992; Buikstra and Ubelaker, 1994; Cox, 2000a). This feature is scored from zero (absent) to four degree of expression: broad deep sulcus, broad shallow sulcus, narrow deep, narrow shallow and smooth-walled sulcus. Absent is considered to be only associated with males and broad shallow with female. Houghton (1974) noticed that there are two types of PAS: type 1:"groove of pregnancy"- sulcus with a scooped appearance consisting of a series of pits, could be found only in women; and type 2: "groove of ligament", a smooth floored sulcus, could be found in both men and women (cited in Cox, 1989; Ubelaker and De La Paz, 2012).

The sacrum is long and narrow and more curved in males than in females (Bass, 1995:216). The sub-pubic angle is U-shape in females but in males tends to be narrower and V-shaped (Mays, 2010:40, see Figure 6.1). Phenice (1969) devised a method for sexing the pelvis in the sub-pubic region based on the ventral arc and sub-pubic concavity (Figure 6.4), which is only present in females, as well as the medial aspect of the ischio-pubic ramus which is broad and flat in males but narrow and sharp in females. She states that her method identifies sex with accuracy in excess of 95%. This method is the most accurate and reliable yet known for estimating sex from the pelvis with an accuracy of between about 88.4% and 100%, and with low intra- and inter-observer error (Meindl et al., 1985a; Sutherland and Suchey, 1991; Ubelaker and Volk, 2002; White and Folkens, 2005:395-8; Klales et al., 2012).

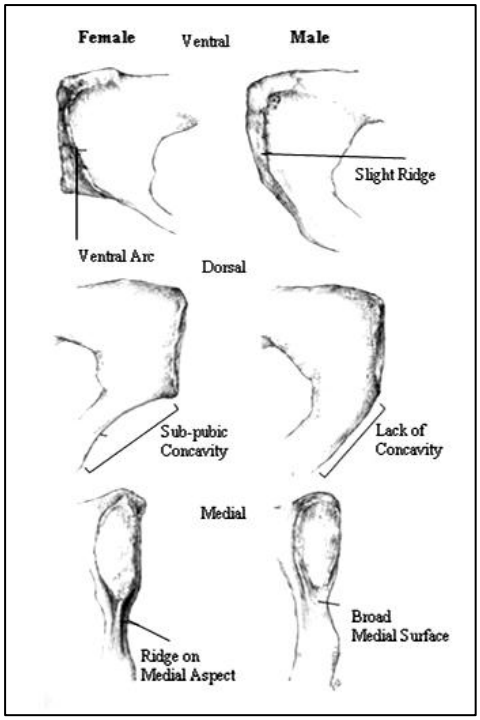


Fig 6.4. Sex-estimation in the sub-pubic region (Phenice, 1969:Figure 1)

(c) Cranial sexual dimorphism

Sex differences in the cranium are well documented and are generally based on differences in morphology traits and dimensions, and the relative prominence of muscle attachments of the skull and facial skeleton in males and females (Meindl and Russell, 1998). Accuracy of sex-estimation from the cranium is estimated to be between 80% and 92% (Meindl et al., 1985a; Krogman and Iscan, 1986; Konigsberg and Hens, 1998; Walker, 2008), and the level of sexual dimorphism is population-specific (van Vark and Schaafoma, 1992). However, the male skull generally tends to be larger, heavier and more robust compared to the female, but males younger than 30 years tend to show female traits (Walker, 1995; Walrath et al., 2004). However, with increasing age females can exhibit a masculine morphology (Meindl et al., 1985a; Walker, 1995). Factors such as environment and diet may influence on the level of robusticity in the skull and mandible which will affect sex-estimation (Walrath et al., 2004). In the current study, twelve sexually dimorphic traits were observed in the skull and mandible (Figures 6.5-7) (Acsádi and Nemeskéri, 1970; Buikstra and Ubelaker, 1994; Bass, 1995; Loth and Henneberg, 1996). When comparing male and female cranial morphology, males have thicker, blunted and rounder supraorbital ridge/margins, but they are sharper in the female; the forehead is more sloped in males with a more marked glabella area, but in females the glabella area is smoother and less prominent and the forehead more

vertically orientated (Acsádi and Nemeskéri, 1970). Older women show heavier supraorbital ridges than younger one (Walker, 1995).

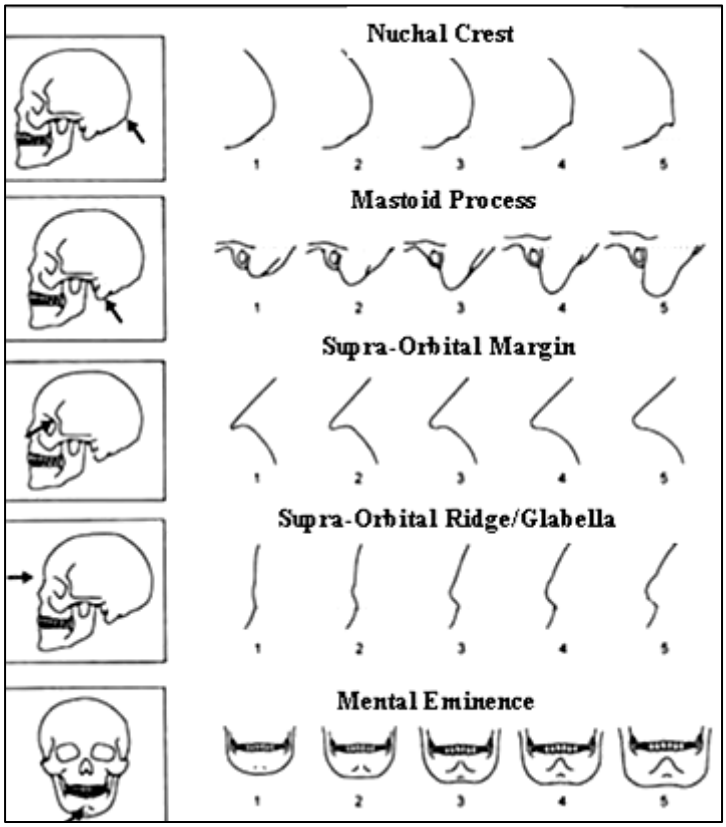


Fig 6.5. Acsádi and Nemeskéri (1970): Standard scoring method for sex-estimation for male and female crania showing the range of expression from 1 (definitely female) to 5 (definitely male) (Buikstra and Ubelaker, 1994:Figure 4)

The nuchal crest tends to be more prominent and enlarged in males (Acsádi and Nemeskéri, 1970; Mays, 2010:43). The chin is usually square in males, but rounded in females (Bass, 1995), and gonial eversion is less marked in females. The mental eminence is more pronounced in males (Acsádi and Nemeskéri, 1970), and the posterior zygomatic process extends as a ridge/crest past the external auditory meatus in males, but not usually in females (Figure 6.6). The mastoid process is larger and blunter in males compared to females, who have a pointed and smaller mastoid process (Bass, 1995).

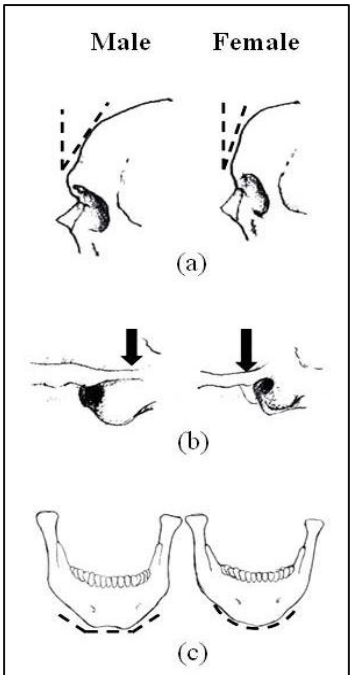


Fig 6.6. Cranial morphological differences between male (left) and female (right) skulls:(a) forehead, (b) posterior zygomatic process, and (c) mandible shape (Bass, 1995)

The mandibular ramus flexure (Figure 6.7) only manifests consistently after puberty and it seems to be a male feature. The accuracy for this method is reported to be between about 94% and 99% for a well preserved mandible (Loth and Henneberg, 1996, 1998).

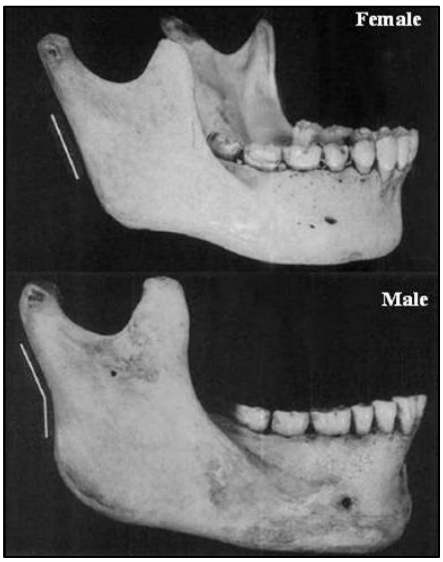


Fig 6.7. Mandibular ramus flexure method of sex-estimation in adults (Loth and Henneberg, 1996)

(d) Long bone measurement and sexual dimorphism

Measurements of bones have been recognized to be another indicator of sex for adults (Brothwell, 1981; Ubelaker, 2004:53; Spradley and Jantz, 2011). However, sex differences in postcranial elements, as for the pelvis and cranium, are difficult to

identify before adolescence (White and Folkens, 2005:387). The adult bones of females are shorter and less robust than males (Ubelaker, 2004:53). The accuracy of sex-estimation using long bone metrical data suggested to be about 80% to higher than 90% (Krogman and Iscan, 1986; Seidemann et al., 1998; White and Folkens, 2005:392; Albanese et al., 2008). However, there can be some size overlap between male and female bone measurements in one population (Ubelaker, 2004:53). Factors such as genetic predisposition, the environment, childhood stress, poor nutrition, war, migration and many unknown factors can influence growth and ultimate size of bones which will influence sex-estimation (St. Hoyme and Iscan, 1989:64; Meindl and Russell, 1998; Asala, 2001). It is suggested that maximum diameters of the femoral, humeral, and radial heads are good indicators of sex in adult skeletons (Ubelaker, 2004:54), and Bass (1995) provides a review of important measurements for long bones (based on measurements from white European populations) that are useful for ex-estimation in adults. Based on Bass (1995) and Ubelaker (2004), six measurements of the long bones were taken (Table 6.1), using sliding digital callipers (to the nearest 0.01mm) and an osteometric board based on descriptions in Buikstra and Ubelaker (1994). These data were used in combination with features of the pelvis and skull. The accuracy of sex-estimation increases to about 90% to 95% when combining skull and long bones(Krogman and Iscan, 1986; Spradley and Jantz, 2011), and increases to 95% when the pelvis and long bones are considered together (Krogman and Iscan, 1986).

Table 6.1. Postcranial measurements used for sex-estimation in adult skeletons (Bass, 1995;Ubelaker, 2004)

Measurements	Male	Female
Femural head diameter	>47.5 mm	<42.5 mm
Femural bicondylar width	>78 mm	<72 mm
Humerus head diameter	>47 mm	<43 mm
*Radial head diameter	>23 mm	<21 mm
Scapula glenoid cavity width	>28.6 mm	<26.1 mm
Clavicle maximum length	>150 mm	<138 mm

(ii) Age-at-Death Estimation

(a) Introduction

Estimation of age-at-death is an essential part of exploring the lives and deaths of past populations (Roberts and Manchester, 2005; Uhl, 2013). Methods of age-estimation are based on observing morphological indicators of growth and degenerative changes in specific areas of the skeleton which reflect biological age (Chamberlain, 2000:105; Cox, 2000:64). However, the process of biological ageing can be influenced by different

factors such as genetic, nutritional, environmental, hormonal, disease, lifestyle, occupational, and individual variation in maturation and degeneration (Scheuer and Black, 2000a:11; O'Connell, 2004; Uhl, 2013). Once growth has ended and adulthood has been reached, estimating age becomes much more difficult in adults than non-adults (Cox, 2000:64; Mays, 2010:89). The ageing techniques developed for adult skeletons are more subjective to use and less accurate when compared to those for non-adults (Uhl, 2013). Adult ageing methods have a tendency to overestimate the age of young individuals and to underestimate the older age-groups (Martrille et al., 2007; Roberts, 2009:137). There remains a need to refine the methods for accurately determining age in older adults and also to standardize the methods between observers (Charles et al., 1989; Brothwell, 1989; Milner et al., 2008). However, age-ranges (e.g., 25-35 years) are always preferred over single year estimates in order to compensate for imprecision in the estimation process (Milner et al., 1989, 2008). Previous studies have shown that applying Bayesian statistical analysis to the age-at-death data overcomes many of the problems associated with age-estimation in skeletal populations (Lucy et al, 1996; Aykroyd et al., 1999; Samworth and Gowland, 2007). However, this study did not use Bayesian method, since it requires a very large and well distributed reference sample, known age material, covering the full age range, with a range of measured age indicators (Aykroyd et al., 1999:9).

The skeletal samples in the current study were all adults, defined to be 18 years and older. This study utilised the most current and well-known methods of age-estimation in adult skeletons, recommended (Buikstra and Ubelaker, 1994; Brickley and McKinley, 2004). The majority of current methods have been established on modern osteological collections with known age-at-death and ancestry. However, there are significant problems involved with controlling the accuracy and precision of these standard methods when applied to unknown archaeological individuals due to limited understanding of population variability (Rissech et al., 2012). However, it is stated that '… available studies indicate that individual variation often swamps populational differences.' (White and Folkens, 2005:363). Nevertheless, in order to minimize errors, in the current study, multiple ageing methods were utilized and care was taken to provide age-ranges for each individual (see Table 6.2), since comprehensive multi-method approaches to age-at-death estimation have proved to be consistently superior to using individual ones (Lovejoy et al., 1985a; Kemekes-Grottenthaler, 2002:51; Ubelaker, 2008). Simultaneously, the pattern changes for each method for each

individual was compared with others in this collection as well as with the results from other methods of aging to provide a more reliable age range for each individual.

Age-at-death estimation methods used in the present study considered young to mature adults and were based on the final stages of skeletal development and epiphyseal union, as well as morphological and degenerative changes (Cox, 2000:64; Ortner, 2003:38). The final stage of skeletal growth includes third molar eruption (van Beek, 1983; Ubelaker, 2004:64), spheno-occipital synchondrosis, fusion of the iliac crest, the ischial tuberosity, the first two segment of the sacrum, and the medial and the sternal end of clavicle (Black and Scheuer, 1996; Scheuer and Black, 2000b), and morphological and degenerative changes include cranial suture closure (Meindl and Lovejoy, 1985), degenerative changes in the auricular surface of the ilium (Lovejoy et al., 1985b), pubic symphysis morphology (Brooks and Suchey, 1990), and dental attrition (Miles, 1962, 1963; Brothwell, 1981). However, other age related traits for identifying older adults were considered including AMTL, osteoporosis (Lovejoy et al., 1985a), and joint disease (osteoarthritis- Rogers and Waldron, 1995).

The age-categories utilized were based on Buikstra and Ubelaker's (1994) recommendations, but to obtain more precise information, the young adult class was divided into two (Table 6.2).

Table 6.2. Age-categories utilised in this study

Age category	Abbreviation	Age range
Young adult 1	YA1	18-25 years
Young adult 2	YA2	26-35 years
Middle adult	MA	36-50 years
Old adult	OA	50+
Adult	AA	18+

(b) Dental eruption

Teeth have morphologically distinct stages of formation, mineralization and eruption, and dental development is recognised to be more closely associated with chronological age than ages based on bone growth, probably due to tighter genetic control, and thus are a widely used method for aging non-adult skeletal remains (Bang, 1989:214; Hillson, 1996:146; White and Folkens, 2005:365). The third molars are the last permanent teeth to erupt and their emergence time covers the period between 15 to 20 years old. The development and formation of the third molar, like other teeth, is variable among the sexes and populations (El-Nofely and Iscan, 1989:240), but is one of the important features used for aging young adults (van Beek, 1983; Hillson, 1996:136;

Ubelaker, 2004:74-Figur 6.8). The development and eruption of the third molar was assessed macroscopically based on Ubelaker (2004- see Figure 6.8). Each skeleton was recorded as either having erupted or almost fully erupted third molars. Individuals with almost erupted third molars, and considering the other ageing methods, were assigned the adult age-category (about 18 or older). This study did not radiograph jaws so that was a limitation.

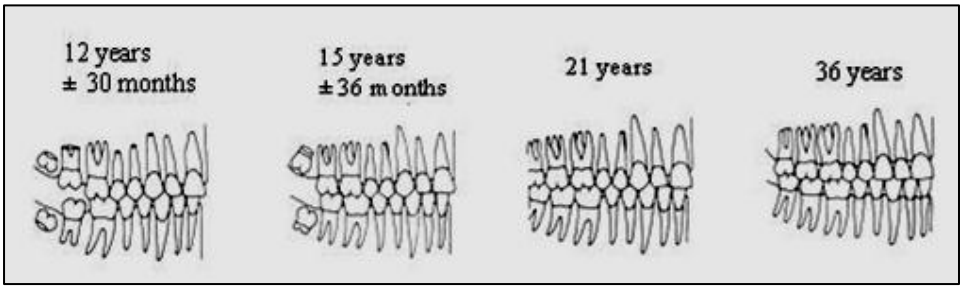


Fig 6.8. The sequence of dental formation and development of the third molar (Ubelaker, 2004:Figure 71)

(c)Dental attrition

The second method used to estimate age from adult teeth was the pattern of dental attrition. Dental attrition is the natural result of mastication stress produced by contact of the teeth with the food eaten (Hillson, 1996:231). Many studies of age-estimation in archaeological skeletons rely on the presence and degree of wear on the occlusal surfaces of teeth (Brothwell, 1981:71; Lovejoy, 1985; Whittaker, 2000:87). However, the degree of attrition in ancient populations has also been attributed to factors such as eating a "coarse-diet", and having "sand" or "grit" incorporated into foodstuffs consumed, the "use of the teeth as tools", and many other unknown factors which will ultimately influence the accuracy of ageing (Molnar, 1971; Smith, 1972, 1984; Whittaker, 2000:87; Mays, 2010:73). Nevertheless, dental wear can still provide valuable age-at-death information, especially in combination with other age indicators (Walker et al., 1991). Miles (1962, 1963) was the first person to develop an estimate of the rate of attrition based on molars (Figure 6.9) in early Medieval (Anglo-Saxons) British populations. Dental attrition was assessed within a skeletal population based on non-adult teeth; this method therefore estimates age from the youngest through the entire age-range of ages to those showing the heaviest wear (Mays, 2010:73).

Brothwell (1981:72) developed a more simplified method for age-grouping based on patterns of dentine exposure on the occlusal surface of the molar teeth (Figure 6.10) in Neolithic to Medieval British skulls following Miles method. Molars were used in both methods, since 'molars demonstrate the greatest degree of consistency in wear

patterns and rates.' (Nowell, 1978:272). However, both methods tend to underage individuals over 50 years old. A combination of Miles (1962, 1963) and Brothwell's (1981) methods was adopted in the present study. The Miles (1963) method was utilized in this study because it is a uniform technique for assessment of dental age with a reasonable degree of accuracy, and thus it is suggested that it is an appropriate and reliable method of ageing for archaeological populations (Kieser et al., 1983; Walker et al., 1991; Mays, 2010). Furthermore, Nowell (1978) evaluated the accuracy of the Miles' method on the population from *Tepe Hissar*. He compared the estimated ages for the mandibles and maxillae of the same individuals with their estimated ages from the pubic symphysis, and indicated the reliability and validity of this method for this site. Kieser et al. (1983) also tested the accuracy of the Miles method on a living Lengua Indian population from Paraguay and the data confirmed its application to ancient populations. Brothwell's (1981) method of aging was used in this study as a comparison for that of Miles (1963) to increase the accuracy of age-estimation in present study. During assessment of attrition related to age changes, however, caution was paid to asymmetry and abnormal patterns due to the fact that these patterns may have occurred as a result of the use of teeth as tools.

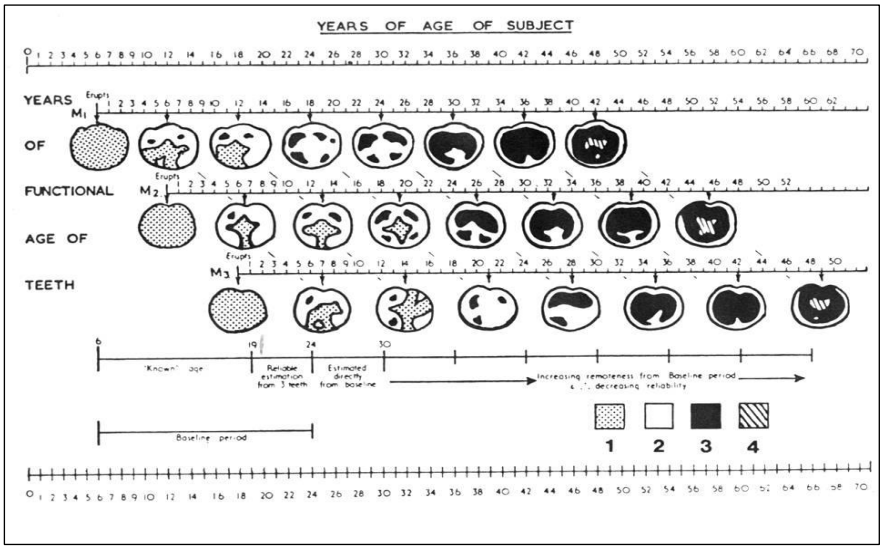


Fig 6.9. Age-estimation system based on attrition of adult teeth (Miles, 1963:Figure 10)

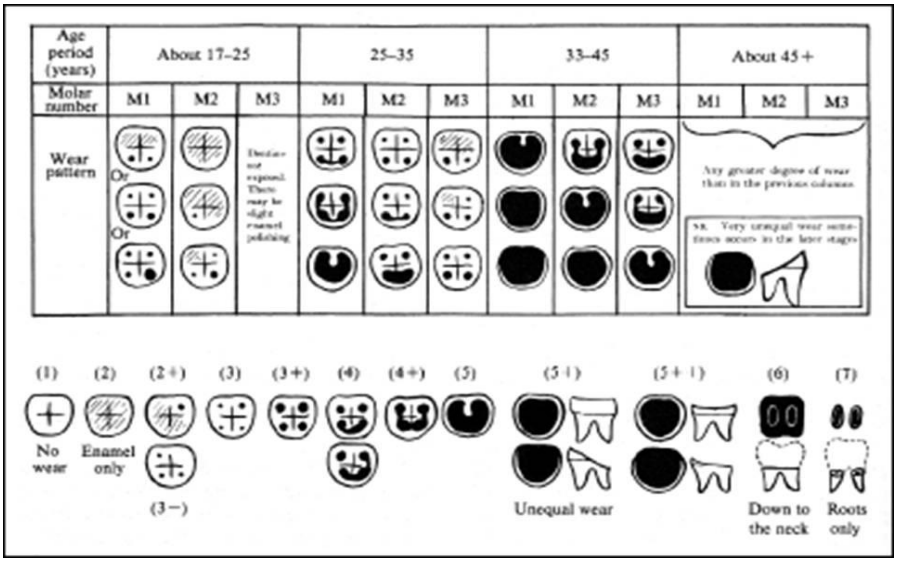


Fig 6.10. Age-estimation system based on attrition of adult teeth (Brothwell, 1981:Figure 3.9)

(d) Epiphyseal fusion

The final fusion of epiphyses is a reliable age indicator and, in combination with dental development and wear, is suitable for use in aging young adults in ancient populations (Walker et al., 1991). The secondary ossification centres of several bones of the skeleton, such as the iliac crest, spheno-occipital syncondrosis, medial and sternal end of clavicle, and the first two segments of the sacrum, complete maturation and fuse during the late second and third decades of life (Cox, 2000:65; Scheuer and Black, 2000b). However, there is variation in bone maturation and ossification by sex, individual, and population. It is also recognised that ossification begins earlier in females than males, and assumed that this was the case in the past (Scheuer and Black, 2000a:16; White and Folkens, 2005:374). In this study, each skeleton was assessed for the final stages of epiphyseal fusion and union of the iliac crest, spheno-occipital syncondrosis, the first two segments of the sacrum, and complete maturation of bones (Scheuer and Black, 2000b), and the medial and sternal end of the clavicle (Black and Scheuer, 1996).

(e) Cranial suture closure

Cranial sutures generally fuse with increasing age and they are characterized by the gradual closure or complete obliteration in older adults. However, in non-adults and younger adults they are usually clearly visible (Ubelaker, 2004:83). There is variability in the timing and closure rates between the sexes, individuals and populations (Todd and Lyon, 1924, 1925; Iscan and Loth, 1989:24; Cox, 2000:66). Furthermore, cranial suture closure correlates weakly with chronological age (Iscan and Loth, 1989:24; Mays,

2010:60), and this method is suggested to be useful only in combination with other adult ageing methods (Cox, 2000:67; Buikstra and Ubelaker, 2004; Mays, 2010:60). The cranial suture closure method of Meindl and Lovejoy (1985) was utilised but only when other aging methods could not be used due to poor preservation.

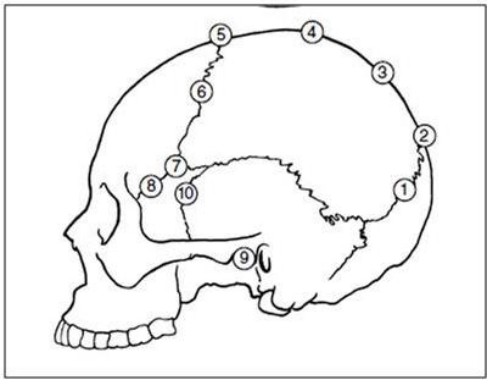


Fig 6.11. Ectocranial suture closure landmarks used for age-at-death estimation in adults (White and Folkens, 2005:370)

Based on Meindl and Lovejoy's (1985), ten suture union landmarks on the ectocranial surface of the skull were scored (Figure 6.11-12) from 0 (open) to 3 (completely fused or obliterated). Each landmark was scored individually on the left side of skull unless missing or damaged on the left, when the right side was used.

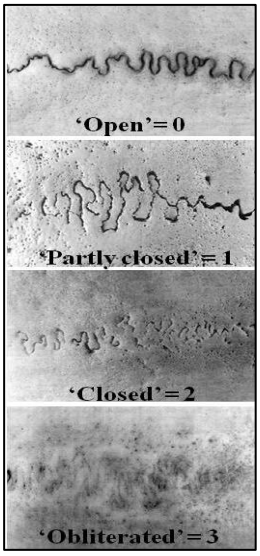


Fig 6.12. Four phases for ectocranial suture closure progress in adults (1cm sutural sites) (Buikstra and Ubelaker, 1994:34-5)

The scores were summed for "vault" and "lateral-anterior" parts of the skull independently and then the average age-range was estimated based on composite scores (Table 6.3).

Table 6.3. Meindl and Lovejoy (1985): Ectocranial suture closure method of age-estimation for "vault" and "lateral-anterior" landmarks (White and Folkens, 2005:370)

Vault sutural age (landmarks 1-7)			**Lateral-anterior sutural age (landmarks 6-10)**		
Composite score	Mean age	Standard deviation	Composite score	Mean age	Standard deviation
0	-	-	0	-	-
1-2	30.5	9.6	1	32	8.3
3-6	34.7	7.8	2	36.2	6.2
7-11	39.4	9.1	3-5	41.1	10
12-15	45.2	12.6	6	43.4	10.7
16-18	48.8	10.5	7-8	45.5	8.9
19-20	51.5	12.6	9-10	51.9	12.5
21	-	-	11-14	56.2	8.5
-	-	-	15	-	-

(f) Morphology of the pubic symphyseal face

The pubic symphysis is the joint between the left and right pubic bones at the anterior of the pelvis, separated by a fibro-cartilaginous joint. Morphological changes to the pubic symphyseal faces are considered a reliable indicator of age in adult skeletons and these changes are the most widely used indicator of age-at-death in adult archaeological populations (Saunders et al., 1992; Bedford et al., 1993; Buikstra and Ubelaker, 1994:21). In young adults the symphyseal face is rugged with transverse horizontal ridges and intervening grooves, but with ageing this surface changes gradually to a smoother appearance with slight marginal osteophytes, a depression, and a pitted or porous surface in the final phase (White and Folkens, 2005:374). Todd was first to describe the progressive morphological changes in the pubic symphysis based on a sample of fully documented white males from the Hamann-Todd skeletal collection (Todd, 1920, 1921; Kemekes-Grottenthaler, 2002:57). He established 10 phases for pubic symphyseal age-estimation, ranging from 18 years to older adults (50+ years). Over the years different researchers have developed this method and reclassified the symphyseal changes in relation to different ages (Brooks, 1955; McKern and Stewart, 1957; Gilbert and McKern, 1973; Suchey, 1979; Meindl et al., 1985b; Katz and Suchey, 1986; Brooks and Suchey, 1990).

The Brooks and Suchey technique (1990) classified the age related morphological changes of the pubic symphysis into six phases applicable to males and females (Figure 6.13). A series of pubic symphyseal casts for different age stages for both sexes are utilised for comparison with pubic symphyses of skeletons. This method was based on a large known age (14 to 99 years) modern male (n=739) and female (n= 273) group autopsied at the Department of Chief Medical Examiner-Coroner, in Los Angeles, USA.

This method produces age-ranges at 95% confidence, but with very large age-ranges and a huge overlap (Brooks and Suchey, 1990; Cox, 2000:69). The authors claim that their method is appropriate for use in archaeological study, since it is based on a large "multiracial" sample of individuals born throughout North and South America, Europe, and Asia, with diverse socio-economic backgrounds. Some research on archaeological and modern skeletons indicate the limitations of using the Suchey-Brooks method, such as inter population variation and observer error, and also a tendency to underage the elderly (Schmitt, 2004; Martrille et al., 2007; Berg, 2008; San Millán et al., 2013). However, the reliability and accuracy of the Suchey-Brooks technique for ageing adult skeletons considered to be the best method (Klepinger et al., 1992; Sakaue, 2006; Lottering et al., 2013).

The Suchey-Brooks method is more precise for adults younger than 40 years (Sakaue, 2006; Martrille et al., 2007). There is a wide range of variability observed in phases III-VI; and difficulty of ageing females, suggesting a relationship either to pregnancy or other unknown factors which do not relate to age. In the current study, in combination with other methods of ageing (see above), the Suchey-Brooks technique was utilised only where preservation permitted. The left pubic symphyseal surface was examined and if that was not present then the right side was substituted and then, based on the similarity of changes to the reference cast, each individual was assigned to a "best fit" age-range. In the case of an "indeterminate" sex individual, the pubic symphyeal surface was assessed using both casts for females and males and then a "reasonable" average age-range determined.

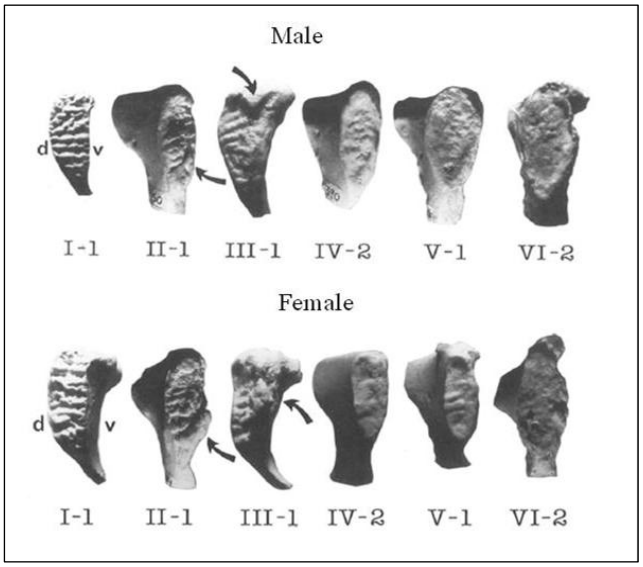


Fig 6.13. Pubic symphysis age scoring system for males and females; d=dorsal, v=ventral (Brooks and Suchey, 1990:Figures 2 and 3)

(g) Degeneration of the auricular surface of the ilium

Morphological changes in the auricular surface of the ilium also provide useful information on age-at-death in adults (Walker et al., 1991). The auricular surface of the ilium is the joint where the ilium articulates with the sacrum (Mays, 2010:60). This method of aging has advantages compared to that of the pubic symphysis, since the auricular surface is more resistant to post-mortem damage in archaeological skeletons than the fragile pubic symphysis (Lovejoy et al., 1985b). Lovejoy and colleagues (1985b) were the first to develop a standard technique for estimating age-at-death in adults based on this area of the skeleton. Their technique describes eight phases of age-related changes and each phase provides a different age-range with 5 or 10 years intervals up to 60 years, and then an open ended category for individuals beyond that age. In the young adult the auricular surface shows a fine-grained surface texture and a pattern of regular billowing with very fine granularity and no porosity or apical activity. These patterns are more pronounced in males than females, which may be attributed to childbearing (Vleeming et al., 1990). However, with increasing age the surface is progressively modified and there is a dramatic decrease in billowing, then the auricular surface turns denser and coarser with microporosity, and in older adults it becomes gradually smoother and porous with bony osteophytes at its edges. Sacroiliac joint diseases and inflammation of the auricular surface may influence the pattern of changes even in young adults (Hodge and Bessette, 1999). The technique is applicable to both sexes and potentially to different populations of different ancestry (Murray and Murray, 1991; Konigsberg and Frankenberg, 1992). This method was tested on archaeological samples and showed a tendency to underestimate the age-at-death of older individuals (≥45 years), and overestimate the age-at-death of younger individuals (34 years old and under) (Saunders et al., 1992; Bedford et al., 1993; Schmitt, 2004).

Changes to the auricular surface are less reliable as a single technique for age-estimation (White and Folkens, 2005; Falys et al., 2006), though, it is suggested that this method can be useful in combination with the other methods age-estimation (Bedford et al., 1993). Buckberry and Chamberlain (2002) revised the method of Lovejoy and colleagues (1985b) based on a known-age skeletal collection from Christ Church Spitalfields, London, and introduced seven phases. However, each phase showed a broader age span than Lovejoy and colleagues, with considerable overlap (Mays, 2010:66). In 2005, Mulhern and Jones tested the revised method on 309 individuals of known sex, age, and race from the Terry and Huntington collections (curated at the

National Museum of Natural History, Smithsonian Institution, Washington DC, USA) and compared their data with the original method of Lovejoy et al. (1985b). The results indicated that the revised method is easy to apply, but it is less accurate than the original method for individuals between 20–49 years of age. However, the revised method is more accurate for older individuals aged about 50 to 69 years (Mulhern and Jones, 2005; San Millán et al., 2013). Falys et al. (2006) tested the accuracy of the revised method on 167 skeletons of known age and sex from St. Bride's, London (17^{th}-19^{th} century A.D.). They noticed a large age-range in difference phases which overlapped between age-categories to a considerable extent, and stated that the auricular surface ageing method is not a promising method to use for age-estimation. Therefore, since there is uncertainty on the absolute accuracy and reliability of the revised method, the Lovejoy et al., (1985b) method of age-estimation was used in combination with other methods of ageing, based on the description for each of the eight single phases, in addition to photographs illustrating the changes for each phase (Figure 6.14).

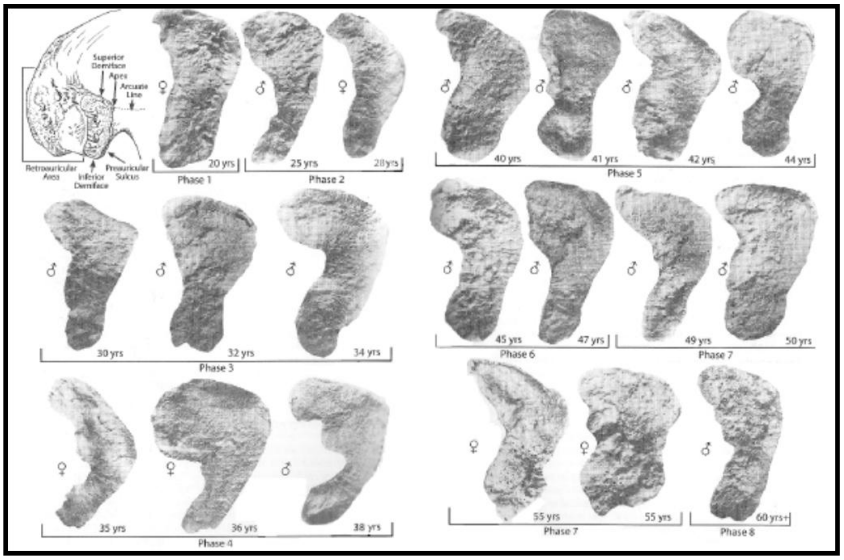


Fig 6.14. Lovejoy et al., (1985b): The eight age phases for the auricular surface in adult males and females (White and Folkens, 2005:Figure 19.9)

6.2.4. Metrical Data: Normal Variation

Metrical data (cranial and dental) was utilized to assess overall biological relationships between the *Tepe Hissar* population within and between periods, and to test the hypotheses proposed in Chapter 1: the inhabitants from Hissar I period are a homogenous population; there are similarities and dissimilarities in biological affinities between individuals/groups of people from the Hissar II and Hissar III; and there is no biological continuity between three periods at *Tepe Hissar*, suggesting each period of the site was occupied by different groups of people. Stature was also estimated for each

period to assess the occurrence of differences in height within and between periods by sex, and to test the same hypotheses above, as well as to test the hypothesis that cultural and economic transitions and possible population changes that occurred at *Tepe Hissar*, and particularly in Hissar II and III, impacted on their general health, leading to childhood stress and short stature.

(i) Craniofacial Measurements

In the current study, craniofacial data were collected from a total of 133 complete and nearly complete adult crania from the three periods at *Tepe Hissar*. This study incorporated 24 standard craniofacial measurements defined by Buikstra and Ubelaker (1994), Brothwell (1981), and Howells (1989). These measurements were taken for all crania and they are recognized to be highly heritable and suitable for exploring biological relationships (Howells, 1973, 1989; Keita, 1988). Standard craniofacial measurements, definitions, and codes utilized in this study are presented in Table 6.4 and Figure 6.15.

Table 6.4. Craniofacial measurements used in this study

Variables	Definition	[1]Buikstra and Ubelaker	[2]Biometrika symbol	[3]Howells code
Neurocranium				
Maximum Cranial Length	Distance between glabella (g) to opsithocranion (op)	*1*	*L*	*GOL*
Maximum Cranial Breadth	Distance between euryon (eu) to euryon (eu)	*2*	*B*	*XCB*
Basion-Bregma Height	Distance between anterior margin of foramen magnum (ba) to bregma (b)	*4*	*H'*	*BBH*
Cranial Base Length	Distance between nasion (n) to basion (ba)	*5*	*LB*	*BNL*
Biauricular Breadth	Distance between the root of zygomatic processes (au-au)	*9*	-	*AUB*
Frontal Chord	Distance between nasion (n) to bregma (b)	*19*	*S'1*	*FRC*
Parietal Chord	Distance between bregma (b) to lambda (l)	*20*	*S'2*	*PAC*
Occipital Chord	Distance between lambda (l) to opisthion	*21*	*S'3*	*OCC*
Foramen Magnum Length	Distance between basion (ba) to opisthion (O)	*22*	*FL*	*FOL*
Foramen Magnum Breadth	Distance between lateral borders of the foramen magnum	*23*	*FB*	-
Mastoid Length	Distance between vertical projection of the mastoid process to the eye-ear plane	*24*	-	*MDH*
Frontal Arc	Distance between nasion (n) to bregma (b)	-	*S1*	-
Parietal Arc	Distance between bregma (b) to lambda (l)	-	*S2*	-
Occipital Arc	Distance between lambda (l) to opisthion	-	*S3*	-
Facial Skeleton				
Bizygomatic Diameter	Greatest breadth between zygomatic arches (zy-zy)	*3*	*J*	*ZYB*
Upper Facial Height	Distance between nasion (n) to alveolar/ or prosthion (pr)	*10*	*G'H*	*NPH*
Minimum Frontal Breadth	Distance from frontotemporal (ft) to frontotemporal (ft)	*11*	*B'*	-
Upper Facial Breadth	Distance between the two external point of frontomalar suture (fmt-fmt)	*12*	-	*FMB*
Nasal Height	Distance between nasion (n) to nasospinal (ns)	*13*	*NH'*	*NLH*
Nasal Breadth	Distance between alar to alar (al-al)	*14*	*NB*	*NLB*
Orbital Breadth	Distance from dacryon (d) to ectoconchion (ec)	*15*	*O'1*	*OBB*
Orbital Height	Maximum distance from superior to inferior orbital margins	*16*	*O2L*	*OBH*
Biorbital Breadth	Direct distance between ectoconchion to ectoconchion (ec-ec)	*17*	-	*EKB*
Interorbital Breadth	Distance between left and right dacryon (d-d)	*18*	*DC*	*DKB*

[1]Buikstra and Ubelaker (1994), [2]Brothwell (1981), [3]Howells (1989)

During metrical analysis, in order to minimize possible error, each skull was placed in the "Frankfurt Horizontal" plane and the measurements were taken using sliding and spreading callipers, or a tape measure, as appropriate. In the case of bilateral measurements the left side was used, and when that was not available then the right side was substituted.

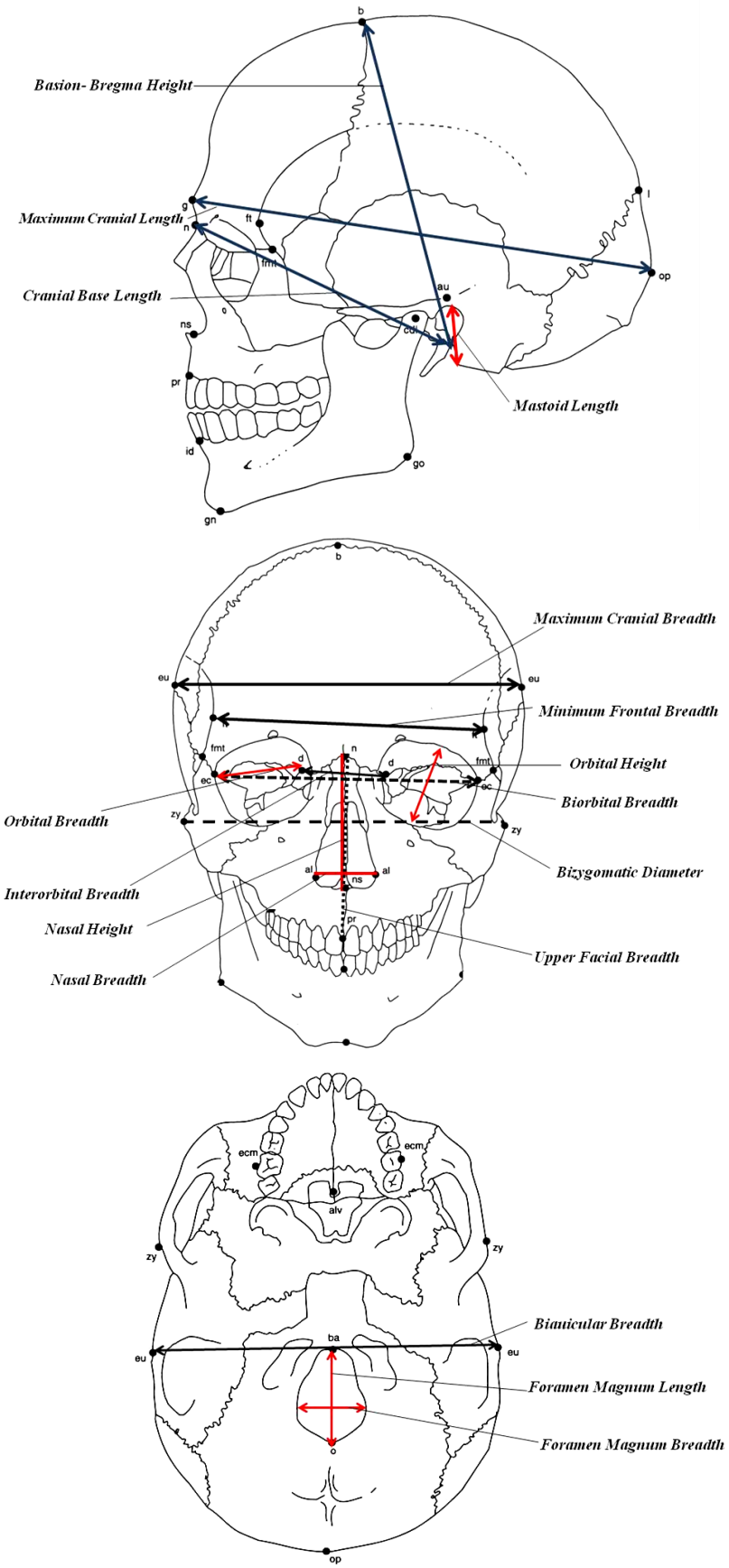


Fig 6.15. Craniofacial measurements collected in this study (Buikstra and Ubelaker, 1994:Figures 39 to 44,P:71-77)

Measurements taken with digital callipers were read to 0.01 mm, and those taken with spreading callipers and a tape measure read to the nearest 0.5 mm. Attention was paid to avoid measuring fragmented, broken and deformed bones (Buikstra and Ubelaker, 1994). To minimize or avoid inter-observer error, all craniometric data used in the present study were recorded by the author and with one set of callipers, and each measurement was taken three times before entering in the recording forms. Tests of inter- and intra-observer error on 15 skulls showed no evidence of a significant difference between measurements (Table 6.11- see below).

(ii) Stature

It is suggested that the most accurate stature estimates from regression equations will be obtained when the population being examined is as similar as possible in body proportions to the population used to create the equations (Raxter et al., 2008). However, since genetic relationships and body proportion similarity are not always clearly known for most archaeological human populations, the criteria for selection of suitable equations are not always straightforward (Vercellotti et al., 2009). Unfortunately, there is no appropriate method of stature estimation available for ancient Iranian populations. In the present study, stature was estimated by measuring the maximum length of the adult lower and upper long bones, and applying regression equations derived from modern white males and females from the United States developed by Trotter (1970) to the measurements. This method is one of the most commonly used regression equations in bioarchaeological and forensic studies (Lukacs and Pal, 2003, Maat, 2005; Raxter et al., 2006; Gunn, 2009:146), and stature estimates are accompanied by an indication of the 95% confidence intervals (Gunn, 2009:146).

Stature estimations were mostly based on the lower limb long bones (tibia and femur) alone, or a combination of measurements of both bones when present since they best reflect living stature (Feldesman et al., 1990; Brothwell and Zakrzewski, 2004). The maximum length of the long bones from the left side was taken using an osteometric board and based on the measurement descriptions in Buikstra and Ubelaker (1994). When bones from the left side were not available then the measurements from the right side were substituted. Pathological and fragmented bones were not used for stature estimation.

(iii) Dental Metrical Analyses

The study of variation in tooth size as a "craniofacial measurement" has the potential to provide valuable information regarding familial relationships among individuals and between human populations (Buikstra and Ubelaker, 1994:61-see Chapter 3). The maximum mesiodistal (MD) and buccolingual (BL) crown diameters were recorded with Mitutoyo digital pointed jaw callipers to the nearest 0.01 mm, following the definitions of Mayhall (1992). This method considers interproximal attrition (Mayhall, 1992, 2000) and has become one of the standard methods for bioarchaeological research (Buikstra and Ubelaker, 1994; Stojanowski, 2005). For each individual the maximum length and width of all emerged and intact permanent tooth crown were measured by holding the calliper beaks parallel to the occlusal plane (Table 6.5, Figure 6.16). In order to minimize possible error, all the measurements were taken with one set of callipers and by the author. The teeth with significant attrition, calculus, caries, and post-mortem damage were not included in the analysis since they influence the accuracy of measurements; they were recorded as missing data (Kieser, 1990:12-13; Mayhall, 1992). Only the measurements taken from the left side were considered for statistical analysis, and if the left tooth was missing then the right measurements were used (Buikstra and Ubelaker, 1994). In order to ensure reliability and accuracy, each measurement was taken three times before recording in the forms. Tests of inter- and intra-observer error on 20 individuals showed no evidence of major difference between dental measurements, the differences being less than 0.3 mm (Table 6.12- see below).

Table 6.5. Maxillary and mandibular crown dimensions used in this study (Mayhall, 1992)

Mesiodistal diameters (MD)	**Buccolingual diameters (BL)**
UI1	UI1
UI2	UI2
UC	UC
***UPM1**	***UPM1**
***UPM2**	***UPM2**
***UM1**	***UM1**
***UM2**	***UM2**
***UM3**	***UM3**
LI1	LI1
LI2	LI2
LC	LC
***LPM1**	***LPM1**
***LPM2**	***LPM2**
***LM1**	***LM1**
***LM2**	***LM2**
***LM3**	***LM3**

*used in multivariate statistical analysis

To increase the sample size, the crown dimensions of the maxillary and mandibular teeth were studied separately, both in univariate and multivariate statistical analyses. Since the sample sizes for MD and BL crown dimensions of the maxillary and mandibular incisors and canines were too small to be meaningful, these measurements were not included in the multivariate statistical analyses. Thus, of a total of 64 tooth measurements recorded, only 20 (10 for the maxilla and 10 for the mandible) were selected for the multivariate statistical analysis (see Table 6.5), or those that were most common among the majority of individuals. These measurements were the MD and BL crown dimensions of maxillary and mandibular premolars and molars. The abbreviation used include: U=upper, L=lower, MD=mesiodistal, BL=buccolingual (faciolingual), I=incisor, PM=premolar, and M=molar.

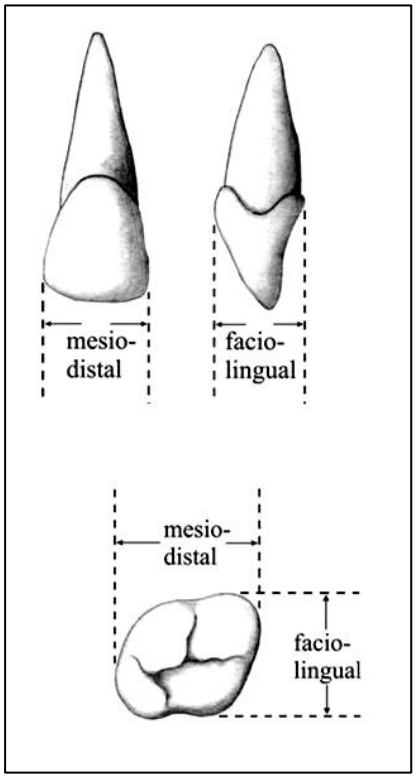


Fig 6.16. The mesiodistal and buccolingual (faciolingual) landmarks for measuring anterior and posterior teeth (Mayhall, 1992:Figures 1 and 2)

6.2.5. Non-Metric Trait Data: Normal Variation

Non-metric traits are "phenotypic" expressions (both genetic and environmental influence) of skeletal and dental anatomy that show considerably different frequencies among human groups, and have the potential for investigating individual and population relationships (see Chapter 3). In this research cranial, post-cranial, and dental non-metric traits were examined in order to explore the pattern of trait frequencies and biological relationships within and between the three periods, and to test the hypotheses

proposed in Chapter 1 (see section 6.2.4). To avoid inter-observer error, the data were collected soley by the author, and to minimize recording intra-observer error each skull, bone, and tooth was examined several times for each trait before entering into the recording forms.

(i) Cranial Non-Metric Traits

Each cranium was scored for the presence or absence of 48 cranial traits shown in Table 6.6 and Figure 6.17, based on Berry and Berry (1967) and Hauser and De Stefano (1989). As there are no previous cranial non-metric trait studies from ancient Iranian populations, it is poorly known what traits were more common among these people, and selecting suitable/applicable cranial traits for this study is not easy. Currently the most comprehensive publications for cranial non-metric traits which describe the traits in detail and provide clear drawings for each are Berry and Berry (1967) and Hauser and De Stefano (1989). These two references are widely regarded as useful to use for biological affinity studies of past populations today, since they were developed based on the evidence of previous ancestral and familial non-metric trait studies worldwide (see Chapter 3). The traits considered in the present research were based on these two trait lists with the intention of obtaining as large a dataset as possible. Some of the traits used in this study have heritability estimates (see Hauser and De Stefano, 1989 and are signed by stars (*) in Table 6.6. The traits from Berry and Berry's list are usually recorded as present or absent, so though traits on Hauser and De Stefano's list can be scored on a graded scale,, this study used present/absent scale for consistency of scoring and reducing possible error.

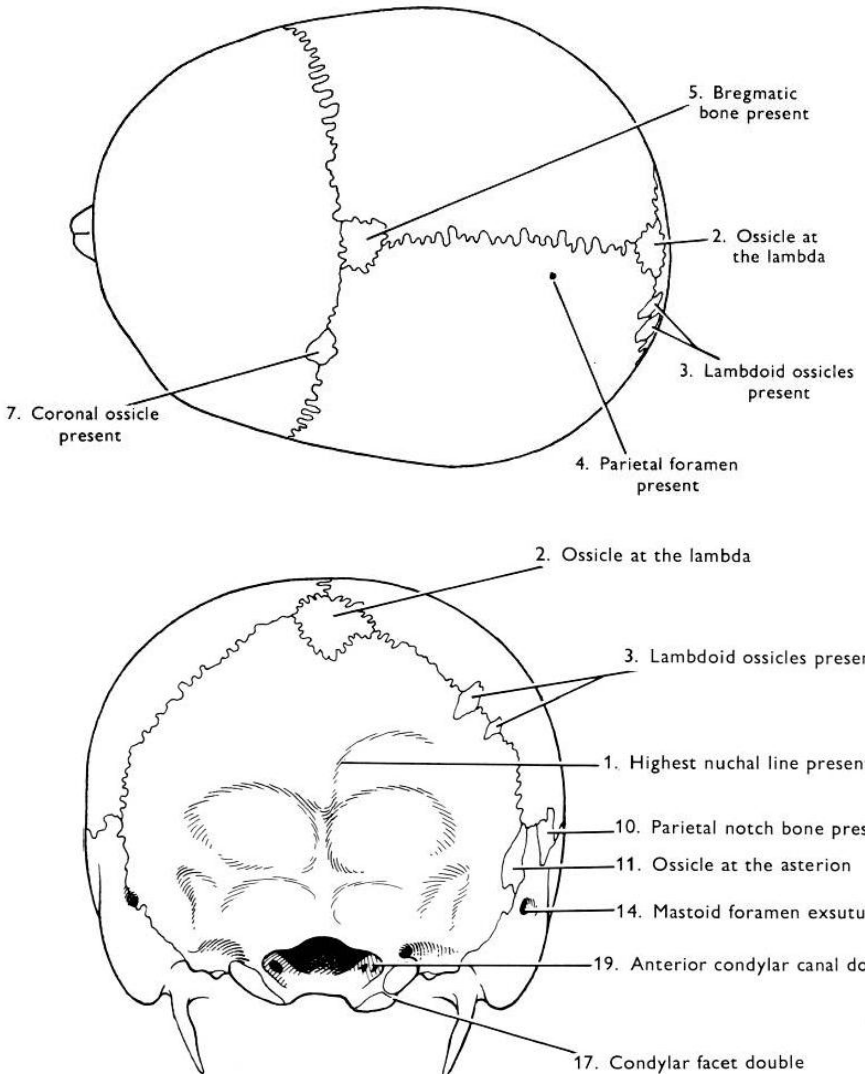
Table 6.6. Cranial non-metric traits and coding used in the study

Code	Variables(Berry and Berry, 1967; Hauser and De Stefano, 1989)	Code	Variables (Hauser and De Stefano, 1989)
1	Highest nuchal-line present	31	Suprameatal spine
2	*Ossicle at lambda	32	Occipital foramen
3	*Lambdoid ossicle present	33	*Frontal grooves
4	*Parietal foramen present	34	Foramen vasalious
5	*Bregmatic bone present	35	Nasal foramina
6	*Metopism	36	Inferior squamous foramen
7	*Coronal ossicle present	37	Inferior parietal foramen
8	*Epipteric bones present	38	Occipitomastoid ossicle
9	*Fronto-temporal articulation	39	Marginal tubercle
10	*Parietal notch bone present	40	Zygomaxillary tubercle
11	*Ossicle at asterion	41	Trochlear spur
12	*Auditory tori present	42	Sutura mendosa
13	Foramen of Huschke present	43	Mental foramen
14	*Mastoid foramen exsutural	44	Sagittal ossicle
15	*Mastoid foramen sutural	45	Supratrochlear notch
16	*Posterior condylar canal	46	*Palatine bridging
17	*Condylar facet double	47	Peterygoalar bridge
18	Precondylar tubercle	48	Squamomastoid suture
19	*Anterior condylar canal double		
20	*Foramen ovale incomplete		
21	*Foramen spinosum open		
22	*Accessory lesser palatine foramen		
23	*Palatine torus		
24	*Maxillary torus		
25	*Zygomatico-facial foramen		
26	*Supra-orbital foramen complete		
27	*Frontal notch or foramen		
28	*Anterior ethmoid foramen exsutural		
29	Posterior ethmoid foramen		
30	*Accessory infraorbital foramen		

*estimated are heritable (indicated in Hauser and De Stefano, 1989)

Each observation was made for both sides for bilateral traits unless the trait was along the midline, or the part of the skull was damaged/lost postmortem on one side. When an observation could not be made due to the poor state of preservation, a missing value was recorded. Non-metric traits are usually scored in two ways, either by "side count" or by "individual count". In the first method, the total number of times each trait occurs on each side of the body must be scored and then the total divided by the total number of sides observed for that trait. However, in the second method, each trait must be recorded as present (regardless of the number of times each trait occurs) if it occurs on either side (left or right), even if the bone or dentition is damaged and only one side is available. Then the total number of individuals with traits present must be divided by the total number of individuals observed for each trait (Green et al., 1979; Buikstra and Ubelaker, 1994). Although the use of grade system potentially provides useful information about the level of genome/environmental influence compared to

dichotomous scoring (Buikstra and Ubelaker, 1994), using this system may increase intra- and inter-observer error in recording and provide inconsistencies in data (Tyrrell, 2000:300). In this study trait frequencies were calculated based on the "individual count" method (Turner and Scott, 1977; Sutter and Mertz, 2004), since this yields the higher estimate (Alt and Vach, 1995; Irish, 2006).



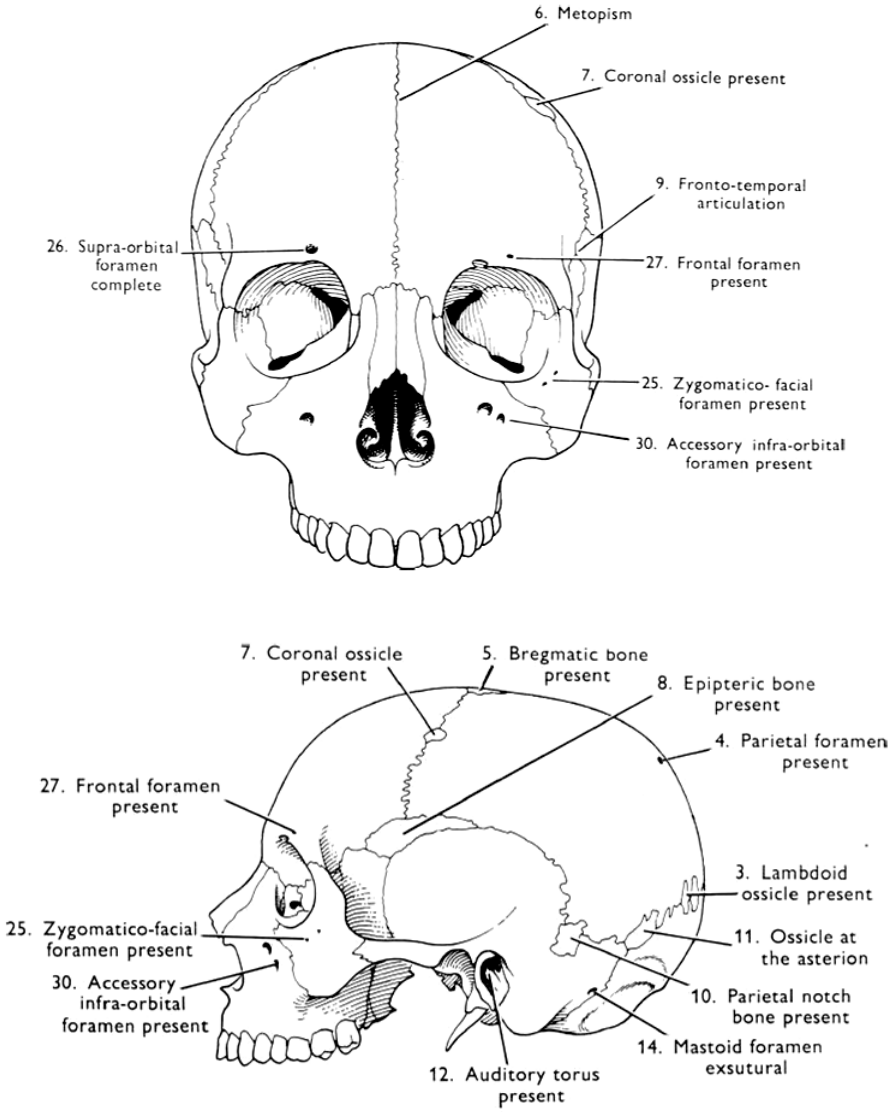


Fig 6.17. Frontal, lateral, posterior, and superior view of the cranium illustrating cranial non-metric traits used in this study (Berry and Berry, 1967:364-365)

(ii) Post-Cranial Non-Metric Traits

Each individual was scored for the presence or absence of 26 post-cranial traits (Table 6.7, Figure 6.18) based on Finnegan (1978). In the case of poor preservation, breakage or the absence of the bone/part of bone a missing value was recorded. This study attempts to use these traits in the same way as cranial and dental traits, because several studies indicated that post-cranial traits express "phenotypic" variations and are useful in biological relationship studies among ancient human populations (see Chapter 3). However, some of them are susceptible to remodelling due to "activity" and this must be considered in interpretation. Nevertheless, a consistency of finding traits linked to biomechanical adaptation/activity alongside other lines of biological and/or

archaeological evidence can provide valuable information about population structure and relatedness (Larsen, 1997:303).

Table 6.7. Post-cranial non-metric traits and coding numbers used in the study (Finnegan, 1978)

Code	Variable	Code	Variable
1	Allen's fossa	14	Acromial articular facet
2	Poirier's facet	15	Suprascapular foramen
3	Plaque	16	Circumflex sulcus
4	Hypotrochanteric fossa	17	Vastus notch
5	Exostosis in trochanteric fossa	18	Vastus fossa
6	Third trochanter	19	Emarginate patella
7	Medial tibial squatting-facet	21	Medial talar facet
8	Lateral tibial squatting-facet	22	Lateral talar extension
9	Supracondyloid process	23	Inferior talar articular surface
10	Septal-aperture	24	Anterior calcaneal facet double
11	Acetabular crease	25	Anterior calcaneal facet absent
12	Preauricular-sulcus	26	Peroneal tubercle present
13	Accessory sacral facets		

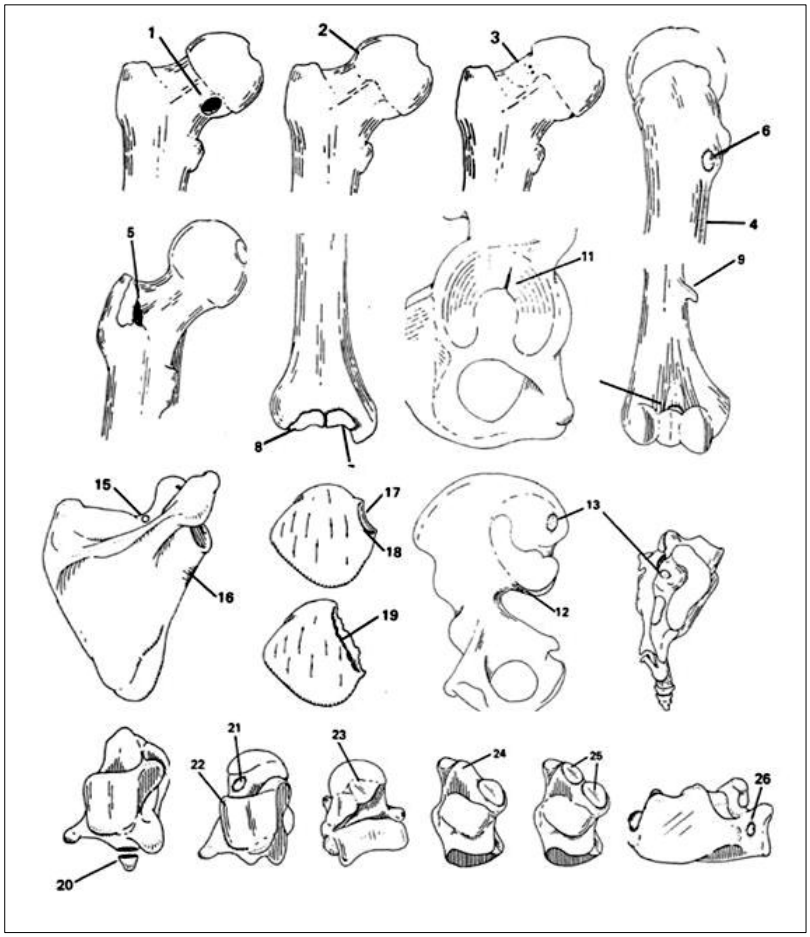


Fig 6.18. Post-cranial non-metric trait used in this study (Finnegan, 1978:28-30)

Each observation was made for both sides and recorded present if a trait occurred on either side (left or right), even if the part of the skeleton was damaged/lost postmortem on one side. Trait frequencies were again calculated based on the

"individual count" method since this yields the higher estimate (Alt and Vach, 1995- see above).

(iii) Dental Non-Metric Traits

Permanent mandibular and maxillary teeth were observed and recorded for the presence or absence of 26 non-metric traits (Table 6.8) based on the classification and description of permanent dental morphological variation developed by Turner et al., (1991- the Arizona State University (ASU), Dental Anthropology System; Scott and Turner, 1997), as recommended by Buikstra and Ubelaker (1994). The ASU system has proven to be a standardized, well established, efficient procedure for scoring dental traits, and is recognised to be an easy and reliable method for comparative studies of dental morphology and biodistance among populations around the world, with minimum inter- and intra-observer error (see Chapter 3). Each tooth was examined macroscopically in the best available light and with a magnifying glass for each trait, using the descriptions of the traits (Turner, et al., 1991; Scott and Turner, 1997- Table 6.8) and comparing teeth with the ASU standard reference dental plaques to help standardize scoring. Each trait was recorded as present or absent. When an observation could not be made due to the poor state of preservation, dental attrition, AMTL, or pathological conditions, it was recorded as a missing value (Turner et al., 1991). The trait frequencies were again calculated based on the "individual count" (Turner and Scott, 1977- see above), i.e. each trait was recorded present if it was present on either side (regardless of the grading system). It is assumed that each individual has only a single piece of genetic information for dental development and each trait, so the examination of one side provides a realistic result (Turner and Scott, 1977; Alt and Vach, 1995; Mayhall, 2000:125; Sutter and Mertz, 2004; Irish, 2006; Scott, 2008:285). The abbreviations used for recording were: L=lower, U=upper, I=incisor, PM=premolar and M=molar.

Table 6.8. Dental non-metric traits and coding numbers used in the study (Turner, et al., 1991)

Maxilla		Mandible	
Variables	**Score**	**Variables**	**Score**
Winging UI1	ASU 1= +	Shoveling LI1	ASU 2-6= +
Shoveling UI1	ASU 2-6= +	Congenital absence LM3	ASU 1= +
Labial curvature UI1	ASU 2-4= +	Lingual cusp variation	ASU 2-9= +
Interruption groove UI2	ASU M, D, MD,Med= +	LPM1	
Tuberculum dentale UI2	ASU 1-6= +	LPM2	
Mesial ridge UC	ASU 1-3= +	X-Groove pattern LM1	ASY X= +
Distal accessory ridge UC	ASU 1-5= +	Y-Groove pattern LM1	ASU Y= +
Distosagital ridge UPM1	ASU 1= +	+-Groove pattern LM1	ASU + = +
Metacone (cusp3)UM3	ASU 1-5= +		
Hypocone (cusp4)	ASU 1-5= +	X-Groove pattern LM2	ASY X= +
UM1		Y-Groove pattern LM2	ASU Y= +
UM2		+-Groove pattern LM2	ASU + = +
UM3			
Metaconulue (cusp5)	ASU 1-5= +	X-Groove pattern LM3	ASY X= +
UM1		Y- Groove pattern LM3	ASU Y= +
UM2		+-Groove pattern LM3	ASU + = +
UM3		Distal trigonid crest LM3	ASU 1= +
Carabelli's trait UMs	ASU 2-7= +	Protostylid LM3	ASU 1-6= +
Parastyle UM3	ASU 1-5= +	Cusp 5 LM1	ASU 1-5= +
Enamel extension UM1	ASU 1-3= +	Cusp 5 LM2	ASU 1-5= +
Congenital absence UM3	ASU 1= +	Cusp 5 LM3	ASU 1-5= +
		Cusp 6 LM3	ASU 1-5= +
		Cusp 7 LM3	ASU 1-4= +
		Enamel extension LM1	ASU 1-3= +
		Cusp number	
		LM1 (5+)	ASU 5+= +
		LM2 (3)	ASU 3= +
		LM2 (5+)	ASU 5+ = +
		LM3 (3)	ASU 3= +
		LM3 (5+)	ASU 5+ = +

6.2.6. Recording of Disease: Abnormal Variation

Skeletal and dental indicators of stress, and metabolic and dental diseases were studied to test the hypothesis (Chapter 1) that the cultural- economic transitions and possible population changes that occurred at *Tepe Hissar*, and particularly in Hissar II and III, impacted on their subsistence economy, the diet people ate, and their general health, and this also differed between males and females.

(i) Skeletal Indicators

Malnutrition or nutritional deprivation is recognized as a major factor for metabolic bone disease occurrence (Ortner et al., 1999; Holick, 2006; Dunnigan and Henderson, 1997- also see Chapter 4). The presence or absence of skeletal indicators of stress and/or dietary deficiency included, porotic hyperostosis and cribra orbitalia, vitamin C deficiency, vitamin D deficiency (including residual rickets/osteomalacia), and osteopenia/osteoporosis were recorded where present.

(a) Porotic hyperostosis (PH) and cribra orbitalia (CO)

The presence or absence of CO was assessed macroscopically in all individuals with at least one orbital roof preserved using the Stuart-Macadam (1991) method. This method describes the appearance of CO in five stages (Figure 6.19) from capillary impressions (stage 1) to more pronounced changes (stage 5) with outgrowth of a trabecular form from the outer table surface of the orbital roof. In this study, a stage of 2 and higher was taken as presence of CO, while other grades was taken to indicate absence. Hyperostotic changes in the cranial vault (frontal, parietal and occipital bones) were assessed visually based on Stuart-Macadam (1985), and Buikstra and Ubelaker (1994). Since the question of the present study was the occurrence and the rates of pH and CO among *Tepe Hissar* population not the degree of severity, and also, for an effective and reliable result, only the presence/absence (Jacobi and Danforth, 2002) of this lesion was considered.

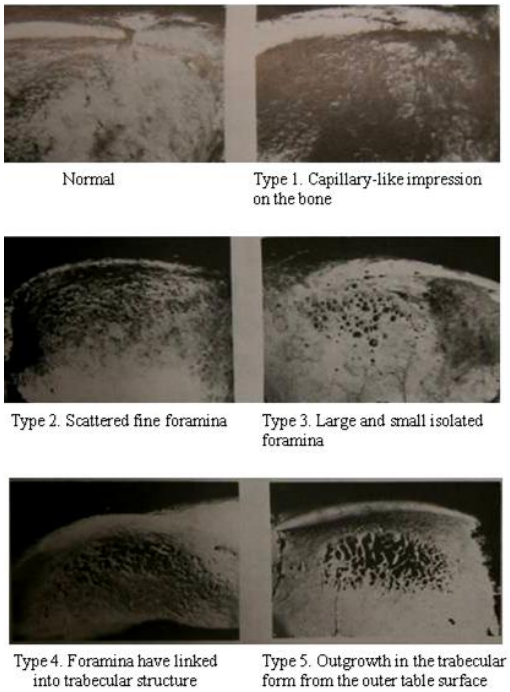


Fig 6.19. Different types of CO lesions (Stuart-Macadam, 1991:108-109)

(b)Vitamin C deficiency-scurvy

Vitamin C is essential for many metabolic processes and maintaining healthy collagen formation in the body (see references in Chapter 4). The manifestation of pathological lesions of scurvy depends on the age of individuals and the length of the deficiency. In adults the pathological lesions of scurvy appear as periodontal disease due to inflammation and chronic bleeding of the gums, subsequent AMTL, bone loss in the long bones of the lower limbs and vertebrae (Brickley and Ives, 2008; Apostolakos and

Halvorsen, 2014), as well as periosteal new bone growth on the long bones as a result of bleeding (Stuart-Macadam, 1989a; Ortner, 2003). However, diagnosis of vitamin C deficiency is not as clear as in children, because the bone lesions are minor or non-specific compared to non-adults (Brickley and Ives, 2008). The manifestations of probable vitamin C deficiency in adults from *Tepe Hissar* were examined macroscopically based on bone changes described by Brickley and Ives (2008), and Ortner (2003). The pattern of new bone formation on the orbits, on the alveolar bone of the jaws, and on the distal ends of long bones, as well as evidence of AMTL, and bone loss for each adult skeleton was recorded. Individuals may suffer scurvy, vitamin D deficiency, and iron deficiency anaemia simultaneously which can influence the accuracy of diagnosis of vitamin C deficiency and its interpretation (Ortner and Mays, 1998; Pimentel, 2003; Murphy and Allen, 2003).

(c)Vitamin D deficiency and osteoporosis

The manifestations of vitamin D deficiency in adults include osteomalacia, residual rickets, and osteopenia/osteoporosis (Holick, 2007; Rahnavard et al., 2010 -see Chapter 4). All individuals were assessed macroscopically for the evidence of vitamin D deficiency based on Ortner (2003), Brickley and Ives (2008), Brickley (2002), and Brickley and colleagues (2005, 2010). This study considered that many macroscopic features of vitamin D deficiency in adults are similar and may overlap with each other (for example osteomalacia and residual rickets, see chapter 4); on the other hand, one individual may have experienced all the manifestation of vitamin D deficiency during life and therefore each skeleton was examined with care.

(ii) Dental Indicators

Like metabolic conditions, the analysis of dental disease can provide important information for dietary and subsistence patterns, and health in past populations, since the pattern of dental diseases are very much influenced by nutritional quality and physical characteristics of the diet (see references in Chapter 4). All the maxillary and mandibular teeth and teeth sockets were examined macroscopically for dental enamel hypoplasia (DEH), dental caries (CAR), calculus (CAL), periodontal disease (PDD), periapical lesions (ABC), ante-mortem tooth loss (AMTL), and dental attrition (ATR). To simplify evaluation the data from the maxilla and mandible, regardless of side, were combined.

(a)Dental enamel hypoplasia (DEH)

DEH is a deficiency in enamel thickness due to physiological stress during growth in childhood and is a valuable indicator for identifying general health and metabolic stress in archaeological populations(see Chapter 4). Since dental attrition can make DEH difficult to study, permanent incisors and canines with less attrition were chosen and hypoplastic lesions were sought with a magnifying glass on the surfaces and recorded as present or absent (Hillson, 2002:167). This approach allows easy and accurate identification of enamel hypoplastic defects regardless of type of defect. Each tooth with evidence of enamel hypoplasia was carefully examined, considering possible association with local trauma which may disrupt formation of just one part of the dentition (Buikstra and Ubelaker, 1994:56; Hillson, 2002:165). Frequency was calculated according to the number of individuals with evidence of DEH on one or more anterior teeth, divided by the total number of individuals with teeth to observed. For the tooth count prevalence, the numbers of teeth with hypoplasia were compared to the total number of teeth observed.

(b)Dental caries (CAR)

Dental caries is an infection characterised by localized fermentation of sugar/carbohydrates and demineralization of dental tissues by bacteria in plaque, identified initially as dark spots on the dentition, potentially leading to the formation of a cavity on the crown or root surface (see Chapter 4). Each tooth was examined macroscopically with a magnifying glass for evidence of a distinct cavity (Lukacs, 1989), and received a single score for the lesions, absent or present. Multiple lesions on a single tooth were not recorded. The total number of teeth affected with caries was compared to the total number of teeth observed for evaluating frequency ("tooth count method"). For "individuals affected", the total number of individuals with evidence of one or more carious lesions was compared to the total number of individuals with teeth to observe.

(c)Calculus (CAL)

Dental calculus is a hard inorganic deposit (initially bacterial plaque) attached to the crown or root surface and can cause inflammation and periodontal disease (see Chapter 4). Unfortunately, due to post-mortem damage many teeth in this study had clear signs that calculus had "eroded" or been lost post-mortem. Due to this issue, and to have useful data, this study recorded the overall presence or absence of calculus by

individuals affected, with the number of individuals with preserved teeth and with evidence of calculus compared to the total number of individuals observed.

(d)Periodontal disease (PDD)

The periodontal tissues include the gingivae, alveolar bone, and periodontal ligaments surrounding the teeth. A progressive inflammation of the periodontal tissues destroys structures around the teeth, with subsequent destruction of the alveolar bone and AMTL (see Chapter 4). Periodontitis was assessed by the presence of resorption of the alveolar bone described by Brothwell (1981:155), and prevalence was calculated as the numbers of individuals with evidence of periodontal disease, regardless of side, compared to the total number of individuals observed.

(e)Periapical lesions (ABC)

In this study, the presence or absence of periapical lesions was examined for each individual based on the criteria defined by Lukacs (1989), Brothwell (1981:156), and Ogden (2008). Exposure of the root was considered as a periapical lesions (abscess or granuloma/cyst cavity- see Chapter 4). Attention was paid to "pseudo-cavities" as a result of post-mortem damage (Brothwell, 1981:156). The number of periapical lesions, regardless of their size, and location, was recorded per tooth socket. The individual count prevalence was calculated according to the number of individuals with one or more lesion compared to the total number of individuals observed with jaws preserved. The tooth socket count prevalence was calculated according to the number of tooth sockets with an abscess/granuloma/or cyst cavity compared to the total number of tooth sockets available for study.

(f)Ante-mortem tooth loss (AMTL)

The loss of teeth before an individual's death is referred to as AMTL. In this research, AMTL was recorded when the tooth socket exhibited clear evidence of alveolar bone remodelling and absorption (Lukacs, 1989:271). The individual count prevalence was calculated according to the number of individuals with jaws preserved with evidence of AMTL compared to the total number of individuals observed. The tooth count prevalence was calculated according to the number of tooth sockets with clear evidence of AMTL compared to the total number of tooth sockets available for study.

(g)Dental attrition (ATR)

The pattern of dental attrition is a useful, albeit subjective in interpretation, indicator for age-at-death estimation as well as for dietary reconstruction and food preparation methods in past populations. The degree of attrition can vary within and between populations (see Chapter 4). In this study, the degree of dental occlusal surface attrition was recorded on scales ranging from 1 to 8 (1 corresponding to absence of wear and 8 to complete attrition of the crown) for every observable tooth, using the system developed by Smith (1984) for incisors, canines, premolars and molars (Figure 6.20). The angle of the occlusal wear of molars was also considered. The teeth from the left side were examined macroscopically for evidence of dental wear, and when left teeth were missing the right teeth were substituted. However, during the recording of dental attrition careful attention was paid to asymmetry which is suggested to be the result of the use of teeth as tools or dental disease.

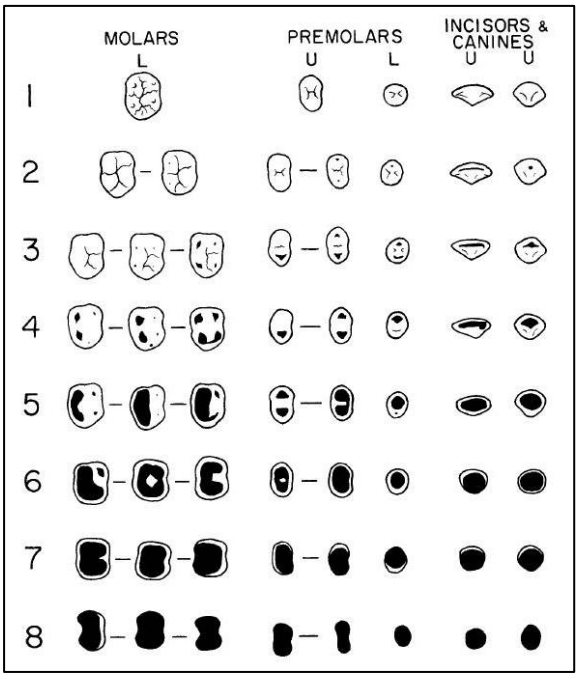


Fig 6.20. Diagram of stages of dental occlusal attrition for different tooth types (Smith, 1984:Figure 3)

6.2.7. Cranial Trauma

The study of skeletal trauma in archaeological population is a direct source of evidence for testing hypotheses about interpersonal conflict and violence (see Chapter 4). Since the head, face and nasal area are most frequently targeted regions of the body in violent attacks (Glencross and Boz, 2014:103), this research only recorded cranial and facial trauma, not long bone fracture. The pattern of cranial trauma was examined in 129 crania available from the three periods at *Tepe Hissar*, to test the hypothesis that

cultural change and possible population influxes at this site, particularly in Hissar II and III, impacted on people and their experience of interpersonal violence. Cranial and facial trauma was analysed based on Ortner (2003), Boylston (2000, 2004), and Buikstra and Ubelaker (1994), as well as forensic anthropological methods (Finegan, 2008; Kimmerle and Baraybar, 2008; Chacón et al., 2008). Cranial trauma was identified as either ante-mortem, well healed or healing wounds, or peri-mortem trauma for those wounds with a lack of healing (Merbs, 1989- see Chapter 4). Evidence of ante-mortem trauma was recorded since it is most likely to be the result of previous interpersonal conflict. The type of peri-mortem fractures were distinguished as blunt, sharp, or projectile force, depending on the morphology and the size of the wound, the evidence of depression, peeling, concentric and radiating fracture lines, internal bevelling, and the polished edges of the wound. Since both post-mortem breaks and peri-mortem fractures show no evidence of bone formation on and around injuries, special attention was paid to distinguish peri-mortem injury accurately, based on the morphology and colour of fracture margin (Boylston, 2000, 2004; Roberts and Manchester, 2005:89).

6.2.8. Carbon and Nitrogen Stable Isotope Analysis

Carbon and nitrogen isotopic signatures of bone collagen were used for dietary reconstruction. The samples were removed from the mid shaft cortex of long bones. The sampling process was carried out by the University of Pennsylvania, Penn Museum, Department of Archaeology and Anthropology (UPM) under the direction of Dr. Janet Monge, and the samples were sent to Durham University for analysis.

(i) Collagen Preparation Laboratory Procedures

Collagen extraction followed a modified Longin procedure (1971; Brown et al., 1988) as described by Smits and colleagues (2010) Initial laboratory sample preparation was conducted at the Department of Archaeology, Durham University by author.

(a)Sample preparation-weighting out

A subsample of bone between 90 and 200 mg was taken from each sample and placed into 15ml glass test tube. Sampling tools were cleaned with a brush and acetone between samples.

(b)Demineralization

To demineralize the bone sample 10ml refrigerated cold 0.5M HCl was added to each test tube. The tubes were covered with parafilm and then pierced for release of any

gas. They were refrigerated at around 4˚C for several days with shaking once a day to keep the bone surface exposed to acid; and change of acid every other day to ensure there was adequate acid for the process of demineralization. This procedure was continued till the bone mineral dissolved and the bone become soft, flexible, floated, or turned translucent. The period of demineralization was variable between samples depending on the level of their preservation. Some bones demineralized in less than one week, while some needed more than two weeks. The demineralized samples were washed with purified water several times using Ezee filters until the sample exhibited a pH of at least 3.0, if needed then a few drops of 0.5 M HCl were added to obtain pH 3.0.

(c)Gelatinization and ultrafiltration

The test tubes with pH 3.0 solution were placed into a heating block for 24 to 48 hours at 75ºC to dissolve and gelatinize the collagen. Once the collagen dissolved, the liquid in each tube was Ezee filtered and transferred into a cleaned ultrafilter tube and then centrifuged for 15 to 20 minutes at a speed of 4000 rpm. The highly concentrated solution retained on the filter was transferred by pipette into a clean pre-weighed plastic tube. The tubes were covered with parafilm and pierced to allow gas release during the freeze-drying process.

(d)Freeze-drying (Lyophilization)

All the tubes were frozen for 12 hours and then transferred to the freeze-dryer for about 48 hours to obtain white, fluffy, purified collagen.

(e)Collagen yield

To obtain the collagen mass each tube was weighed and the original weight subtracted. The percentage collagen yield was calculated as:

Collagen mass/the original mass dry bone weight × 100%

Samples with less than 1% yield were rejected (Ambrose, 1990) for mass spectrometry.

(f)Mass spectrometry stable isotope measurements

The final processing stage was carried out in the Department of Earth Sciences, Durham University, Stable Isotope Laboratory. In this step, approximately between 0.3 to 0.35mg of purified freeze-dried collagen was weighed out into tin capsules (Elemental Microanalysis Ltd). The capsules were sealed by pressing and folding to a cube shape to protect the collagen. Each sample was measured in duplicate. During weighing and sealing of the collagen samples special attention was paid to avoid

contamination, so for each sample all instruments which had been used already (e.g., tweezers, lab plate), were cleaned with acetone. The stable isotope abundances were measured in isotope ratio mass spectrometers (IRMS- use to measure, to a high level of precision, the C and N isotope ratios within the inorganic fraction of tooth and bone samples) in the Department of Earth Sciences, Durham University, Stable Isotope Laboratory.

(g)Collagen quality control

The isotopic results were checked for quality (see Chapter 5). Samples outside 2.9 to 3.6 for C:N were considered unreliable and discarded (DeNiro, 1985). Likewise, if the mean carbon and nitrogen concentrations for duplicated samples fell outside 35-50% (C %) or 11-16% (N %) they were rejected.

6.2.9. Statistical Treatment

Statistical analysis is important to achieve standard valid comparisons among populations under study (Chamberlain, 2006:41). Statistical comparison considered the *Centre for Archaeology Guidelines* (2002) recommendations. All tests were conducted in SPSS 20 with the significance level set at 0.05, so only p-values less than 0.05 were considered significant. The significant differences in the level of preservation, as well as sex and age distributions within and between the *Tepe Hissar* populations were tested using the chi-squared statistic (Chamberlain, 2006:43-44). For calculating and testing significant differences in mean stature, t-test and Kolmogorov–Smirnov test were employed.

To examine the differences between craniofacial measurements, as well as between dental measurements among the sexes and periods, the original metrical data were used for descriptive statistical analysis and for testing for significant differences, performing a one-way analysis of variance (ANOVA). Given the fragmentary nature of many of the archaeological human skeletal remains, some measurements were missing. The missing values for the craniofacial data of Hissar II did not exceed 11% of the sample, with that amount being estimated for interorbital length (11%). In Hissar III the estimated missing values for all the measurements, except foraminal breadth (18%) were less than 11.4%. However, among two crania from Hissar I, one was better preserved than the other and was used in multivariate statistical analysis. In the case of dental metrical data, the percentage of missing values did not exceed 14% of the samples. Multivariate statistical analyses do not allow for missing variables and require

complete data, thus this small proportion of measurements had to be imputed using the multiple imputation procedure. The multiple imputation method replaces each missing measurement with a reasonable value (Sokal and Rohlf, 1995). This procedure is commonly used in many bioarchaeological population studies (Powell, 1993; Pietrusewsky, 1994, 1999; Pinhasi and von Cramon-Taubadel, 2009; von Cramon-Taubadel and Pinhasi, 2011). The original raw data and the imputed data for both craniofacial and dental measurements were compared, and a paired t-test showed no statistically significant difference between the mean of the original measurements and the imputed data (Table 6.9 and 6.10).

Table 6.9. Paired t-test: comparing craniofacial metric imputation

Measurements	*t*	*P*[1]	Measurements	*t*	*P*[1]
Maximum Cranial Length	.914	.409	Bizygomatic Diameter	.702	.625
Maximum Cranial Breadth	.603	.549	Upper Facial Height	.485	.617
Basion-Bregma Height	-.137	.870	Minimum Frontal Breadth	.88	.517
Cranial Base Length	.304	.739	Upper Facial Breadth	.701	.166
Biauricular Breadth	.195	.718	Nasal Height	.204	.816
Frontal Chord	.384	.762	Nasal Breadth	.717	.184
Parietal Chord	.733	.196	Orbital Breadth	-.468	.790
Occipital Chord	-.112	.509	Orbital Height	.225	.296
Foramen Magnum Length	.921	.505	Biorbital Breadth	1.352	.183
Foramen Magnum Breadth	1.712	.389	Interorbital Breadth	.259	.753
Mastoid Length	1.223	0.202	Parietal Arc	.679	.084
Frontal Arc	0.405	0.682	Occipital Arc	-.196	.894

[1] differences is significant at 0.05 level

Table 6.10. Paired t-test: comparing dental metric imputation

Measurements	*t*	*P*[1]	Measurements	*t*	*P*[1]
LPM1MD	1.242	.298	UPM1MD	.128	.697
LPM1BL	.281	.839	UPM1BL	.237	.727
LPM2MD	2.201	.092	UPM2MD	-.126	.768
LPM2BL	.361	.781	UPM2BL	.478	.698
LM1MD	.118	.949	UM1MD	.147	.932
LM1BL	.565	.439	UM1BL	.548	.650
LM2MD	.558	.43	UM2MD	.564	.640
LM2BL	-.786	.504	UM2BL	.791	.541
LM3MD	.497	.685	UM3MD	.687	.562
LM3BL	.756	.521	UM3BL	-.762	.537

[1] differences is significant at 0.05 level

To evaluate biological distance or similarity between individuals, Mahalanobis generalized distances (d^2) and principal components analysis (PCA) were calculated on the craniofacial and dental metrical data. Mahalanobis generalised distance, or the summed squared differences, is a function of mean values of the groups compared, and the pooled variances and covariances provide a single quantitative measure of dissimilarity between pairs of groups (Pietrusewsky, 2008:495). This method is ideal for investigating morphological distances between crania of individuals and populations. The larger the distance between two individuals or groups, the less similar are the two

individuals or groups (Pietrusewsky, 2008:495). Mahalanobis generalized distances (d^2) have been widely and successfully applied to many prehistoric human craniofacial metrical analyses (Stefan, 1999; Powell and Neves, 1999; Pietrusewsky, 1994, 2006; Matsumura, 2006; Stojanowski and Schillaci, 2006; Keita and Boyce, 2008; Stynder, 2009), as well as in studies of dental metrical variation (Stojanowski, 2003; Hanihara, 2010; Kaburagi et al., 2010).

PCA is a descriptive measure that focuses on the relationship among the total number of variables in a single sample, and aids identification of common underlying patterns of variation throughout an examination of their shared underlying factors (Pietrusewsky, 2008:493). PCA eliminates intercorrelation between the variables and provides components which are combinations of the original variables (Sciulli et al., 2003). The first principal component includes the most variation among individuals in all measurements, and the following principal components contain reducing amounts of the total variation, and all are uncorrelated with each other (Ousley and Jones, 2010). This method has been used in many human craniofacial metrical analyses (Powell and Neves, 1999; Key and Jantz, 1990; Roseman and Weaver, 2004; Keita, 2004; Poshekhonova, 2011; Ousley and Jones, 2010) and dental metrical variation studies in archaeological populations (Lukacs and Hemphill, 1993; Hanihara and Ishida, 2005; Stojanowski et al., 2007; Morita et al., 2012). In the last stage hierarchical cluster analysis (HCA) is used. For the current study, Ward's method (Ward, 1963) and the Euclidian distance clustering algorithm was used to illustrate the biological relationship between samples based on Mahalanobis generalised distances (d^2) matrix. This method clusters individuals with the smallest loss of information (Ward, 1963). To aid interpretation the results of PCA, scatter plots of the first and second principal component were drawn.

The frequencies of cranial, post-cranial, and dental non-metric traits were compared using chi-square tests of significance, assuming that populations sharing common morphological traits are likely to be more closely related than those who show many differences.

The chi-square test was employed for comparing the significant differences in the prevalence of metabolic and dental disease rates within and between the *Tepe Hissar* population groups by sex and age category. In the case of small sample sizes not meeting the assumptions of the chi-square test, Fisher's exact test was used (Fletcher and Lock, 2005). These calculations were conducted both in Excel and SPSS 20.

The significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between males and females in each period were tested using Mann-Whitney test, and between different age groups were tested using the Kruskal-Wallis test. To test the significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between three periods by pooled sex were tested using the Kruskal- Wallis test and Levene's test.

Table 6.11. Paired t-test: a test of craniofacial metric inter-observer error

Measurements	***t***	***P*[1]**	**Measurements**	***t***	***P*[1]**
Maximum Cranial Length	1.231	.230	Bizygomatic Diameter	1.702	.88
Maximum Cranial Breadth	1.648	.87	Upper Facial Height	.485	.617
Basion-Bregma Height	-.625	.538	Minimum Frontal Breadth	1.225	.233
Cranial Base Length	-.874	.391	Upper Facial Breadth	-1.410	.064
Biauricular Breadth	-.721	.478	Nasal Height	-.425	.675
Frontal Chord	1.760	.091	Nasal Breadth	-1.345	.245
Parietal Chord	-1.298	.207	Orbital Breadth	1.232	.124
Occipital Chord	-2.138	.063	Orbital Height	-.576	.496
Foramen Magnum Length	-1.558	.205	Biorbital Breadth	1.169	.178
Foramen Magnum Breadth	1.257	.221	Interorbital Breadth	1.045	.153
Mastoid Length	1.956	.098	Parietal Arc	-.677	.484
Frontal Arc	1.415	.109	Occipital Arc	-.481	.689

Table.6.12. Paired t-test: a test of dental metric inter-observer error

Measurement	***t***	***P*[1]**	**Measurements**	***t***	***P*[1]**
I1MD	.083	.935	M1MD	2.026	.062
I1BL	1.419	.178	M1BL	-.859	.405
I2MD	-1.224	.241	M2MD	.187	.854
I2BL	-.974	.346	M2BL	-1.896	.079
CMD	.510	.618	M3MD	-.790	.443
CBL	2.380	.032	M3BL	-.034	.973
PM1MD	.767	.456			
PM1BL	-.135	.894			
PM2MD	-.454	.657			
PM2BL	-1.703	.111			

This research did not do DNA analysis, geometric morphometric analysis, or mobility stable isotopic analysis to corroborate the findings regarding population affinities; and also did not record joint disease, long bone trauma, neoplastic, congenital and infectious disease, and Harris lines, due to time and funding/research budget limitations.

The next chapter describes the results of the analyses, including comparative statistical analysis of the data within and between periods.

Chapter 7 : RESULTS

This chapter presents the results of the analysis of the level of preservation, palaeodemography, metric and non-metric traits, metabolic and dental disease, cranial trauma, and dietary isotopes for the *Tepe Hissar* population by period and statistical comparisons between periods. The primary data collected is attached in Appendix 2.

7.1. Preservation

(i) Hissar I

There were a total of 28 skeletons observed from Hissar I, and the majority were in a poor state of preservation. Almost 80% of females and 92% of males were in a poor state (Table7.1,Figure7.1). These differences were not significant among females and males (X^2=1.568, p=0.457), nor between the five age-categories (X^2=3.920, p=0.270).

Table 7.1. Hissar I: Skeletal preservation by sex and age

	Preservation	**Good (>75%)**		**Partial (25-75%)**		**Poor (<25%)**	
		NO.	*%*	*NO.*	*%*	*NO.*	*%*
Sex	Male	0	0%	1	7%	13	93%
	Female	0	0%	2	20%	8	80%
	Indeterminate*	0	0%	0	0%	4	100%
Age	YA1(18-25)	0	0%	2	29%	5	71%
	YA2(26-35)	0	0%	1	12%	7	88%
	MA(36-50)	0	0%	0	0%	2	100%
	OA(50+)	0	0%	0	0%	0	0%
	AA**(18+)	0	0%	0	0%	11	100%
	Total	0	0%	3	11%	25	89%

*indeterminate=unsexed adult, **AA=unaged adult

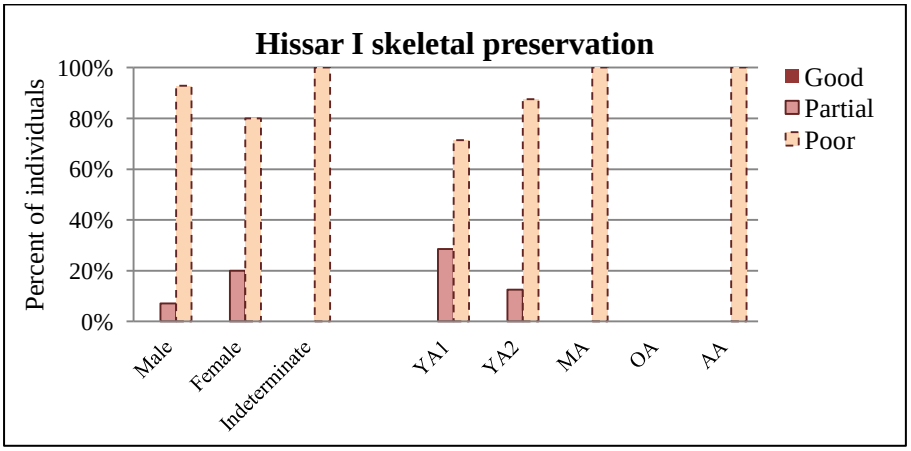


Fig 7.1. Hissar I: Skeletal preservation by sex and age-group

(ii) Hissar II

A total of 53 Hissar II individuals were observed; 8% were in a good state of preservation, of which 12% were male and 7% were female. Almost 18% of YA1 had

well preserved skeletons. However, 52% of skeleton were in a poor state of preservation and 40% were in a partial (Table7.2, Figure7.2). This was not significant between the sexes (X^2=5.388, p=0.250), but significant in the five age-categories (X^2=22.510, p=0.004).

Table 7.2. Hissar II: Skeletal preservation by sex and age

	Preservation	**Good (>75%)**		**Partial (25-75%)**		**Poor (<25%)**	
		No.	*%*	*No.*	*%*	*No.*	*%*
Sex	Male	2	12%	7	41%	8	47%
	Female	2	7%	14	45%	15	48%
	Indeterminate*	0	0%	0	0%	5	100%
Age	YA1(18-25)	2	18%	2	18%	7	64%
	YA2(26-35)	1	11%	5	56%	3	33%
	MA(36-50)	1	11%	7	78%	1	11%
	OA(50+)	0	0%	3	100%	0	0%
	AA**(18+)	0	0%	4	19%	17	81%
	Total	4	8%	21	40%	28	52%

*indeterminate=unsexed adult, **AA= unaged adul

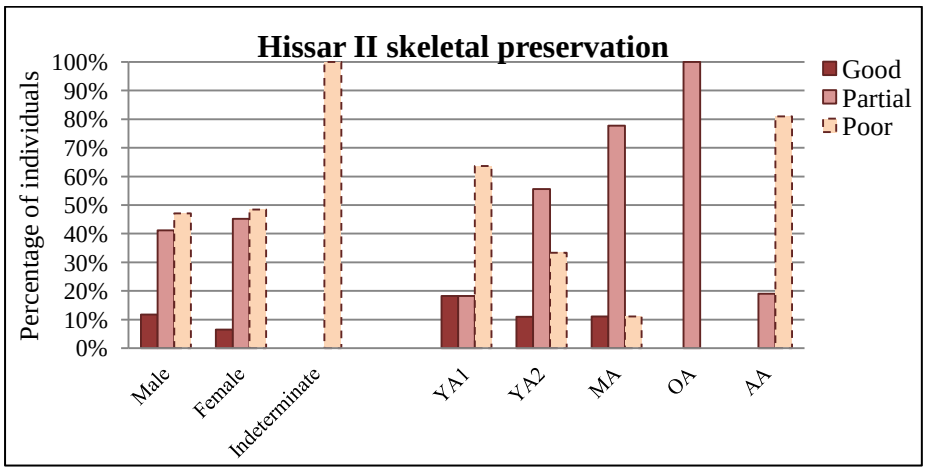


Fig 7.2. Hissar II: Skeletal preservation by sex and age-group

(iii) Hissar III

There were 287 individuals available for study from Hissar III, and the largest part were in a partial state of preservation (49%). Almost 9% were good while 42% were poor. Among females 12%, 47%, and 41% were in a good, partial and poor state of preservation, respectively. Almost 17% and 16% of YA2 and MA were in good condition, respectively (Table7.3, Figure7.3). These differences were significant among females and males (X^2=30.918, p=0.000) and the five age-categories (X^2=73.094, p=0.000).

Table 7.3. Hissar III: Skeletal preservation by sex and age

Preservation		Good (>75%)		Partial (25-75%)		Poor (<25%)	
		NO.	*%*	*NO.*	*%*	*NO.*	*%*
Sex	Male	12	9%	80	57%	49	34%
	Female	15	12%	59	47%	53	41%
	Indeterminate*	0	0%	0	0%	19	100%
Age	YA1(18-25)	1	3%	18	60%	11	37%
	YA2(26-35)	14	17%	47	56%	23	27%
	MA(36-50)	12	16%	46	61%	17	23%
	OA(50+)	0	0%	6	86%	1	14%
	AA**(18+)	0	0%	22	24%	69	76%
	Total	27	9%	139	49%	121	42%

*indeterminate=unsexed adult, **AA= unaged adult

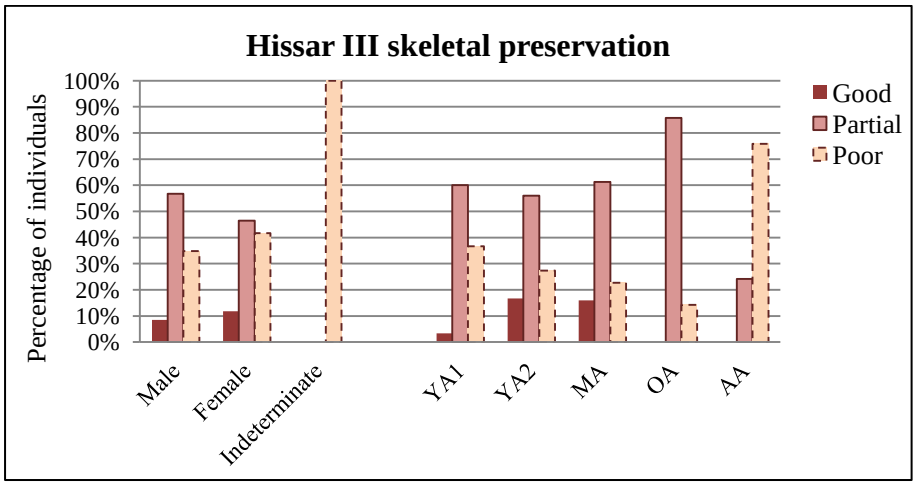


Fig 7.3. Hissar III: Skeletal preservation by sex and age-group

7.2. Palaeodemographic Profile

7.2.1. Hissar I

(i) Sex

Table 7.4 and Figure 7.4 illustrate the sex distribution for Hissar I. Fourteen (50%) of the 28 individuals were estimated to be male, 10 were female (35.7%), and 4 (14.3%) were "indeterminate". There was no significant differences between distribution of males and females in the samples for this period (X^2= 5.924, p=0.066).

Table 7.4. Hissar I: Sex distribution

Sex distribution	*No.*	*%*
Male	14	50%
Female	10	35.7%
Indeterminate	4	14.3%
Total	28	100%

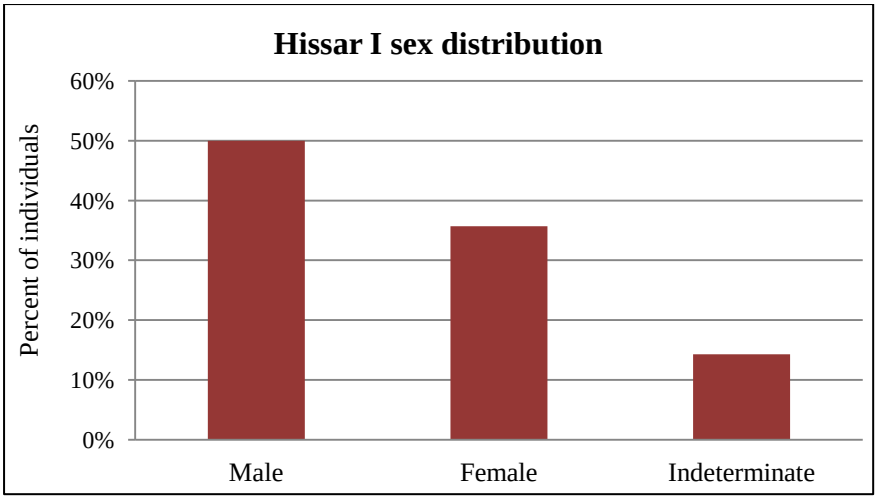


Fig 7.4. Hissar I: Sex distribution (%)

(ii) Age-at-death distribution

The age-at-death distribution for Hissar I can be found in Table7.5 and Figure7.5. Seventeen of the 28 adult skeletons could be placed into an age-category and eleven (39%) adults of unknown age were labelled "adult" (AA). The proportion of individuals who died under 35 years old was higher than other age-groups in this period.

Table 7.5. Hissar I: Age-at-death distribution by sex

		Male		**Female**		**Indeterminate**		**Total**	
Age-category	***Age***	*NO.*	*%*	*NO.*	*%*	*NO.*	*%*	*NO.*	*%*
YA1	18-25	2	14.3%	5	50%	0	0%	7	25%
YA2	26-35	7	50%	1	10%	0	0%	8	28.6%
MA	36-50	0	0%	1	10%	1	25%	2	7%
OA	50+	0	0%	0	0%	0	0%	0	0%
AA	18+	5	36%	3	30%	3	75%	11	39%
Total	-	14	100%	10	100%	4	100%	28	100%

Figure 7.5 shows that there were more young adults dying in the first and second age-groups. The proportion of YA1 female deaths was higher (50%) than male (14.3%). In contrast, for YA2, the number of males increased to 50% when compared to females (10%). The mortality rate declined with age in the over 36 year old group in this period (significant (X^2=13.206, p=0.040); but one must consider the small sample size.

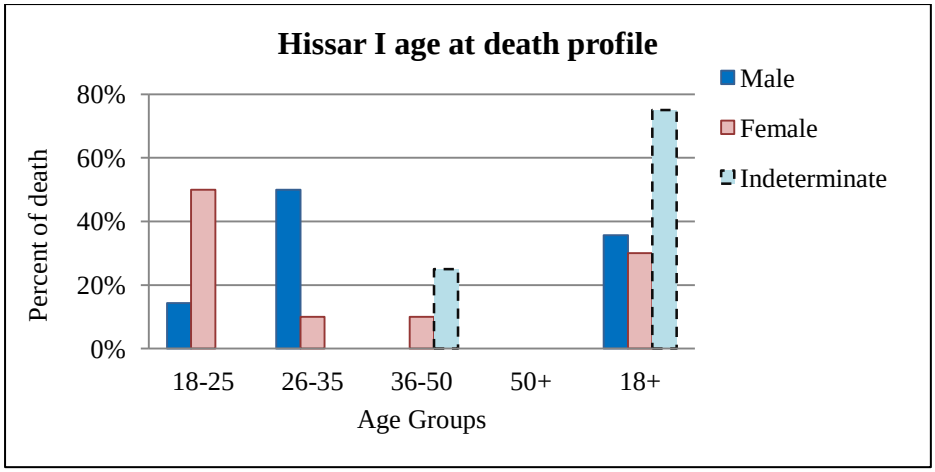


Fig 7.5. Hissar I: Age-at-death distribution by sex

7.2.2. Hissar II

(i) Sex

Table 7.6 and Figure 7.6 illustrate the sex distribution for individuals. Seventeen (32.1%) were estimated to be male, 31 (58.5%) were female and 5 (9.4%) were of "indeterminate" sex. There was a significant difference between distribution of females and males (X^2=19.170, p= 0.000).

Table 7.6. Hissar II: Sex distribution

Sex distribution	***No.***	***%***
Male	17	32.1%
Female	31	58.5%
Indeterminate	5	9.4%
Total	53	100%

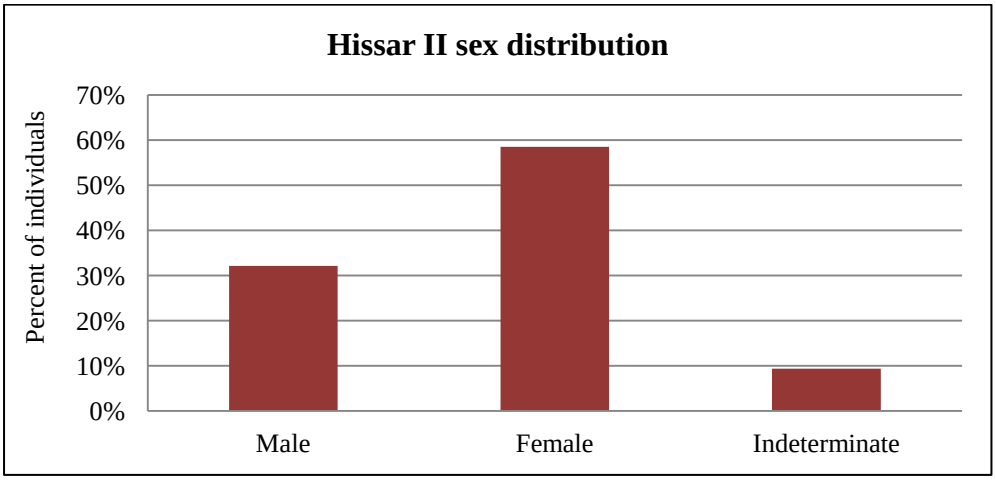


Fig 7.6. Hissar II: Sex distribution (%)

(ii) Age-at-death distribution

The age-at-death distribution can be found in Table 7.7 and Figure 7.7. Thirty-two of the 53 adults could be aged and 21 individuals (39.6%) were designated as "unaged adult" (AA). In total the proportion of individuals under 25 years old was lower (21%) in this period than in Hissar I (25%).

Table 7.7. Hissar II: Age-at-death distribution by sex

		Male		**Female**		**Indeterminate**		**Total**	
Age-category	***Age***	*NO.*	*%*	*NO.*	*%*	*NO.*	*%*	*NO.*	*%*
YA1	18-25	0	0%	10	32.3%	1	20%	11	21%
YA2	26-35	5	29.4%	4	12.9%	0	0%	9	17%
MA	36-50	5	29.4%	4	12.9%	0	0%	9	17%
OA	50+	1	5.9%	2	6.5%	0	0%	3	6%
AA	18+	6	35.3%	11	35.5%	4	80%	21	39.6%
Total	-	17	100%	31	100%	5	100%	53	100%

Figure 7.7 illustrates that the % deaths in YA1 increased to 4% when compared to MA and YA2. This increase was seen in YA1 females (32.3%), but not in males. The % of deaths among YA2 and MA males increased to 29.4% compared to females at that age (12.9%). The number of death among OA declined by about 15% compared to YA1; the female rate was higher than for males. However, there were no statistically significant differences in the age at death distribution among males and females (X^2=13.496, p=0.096).

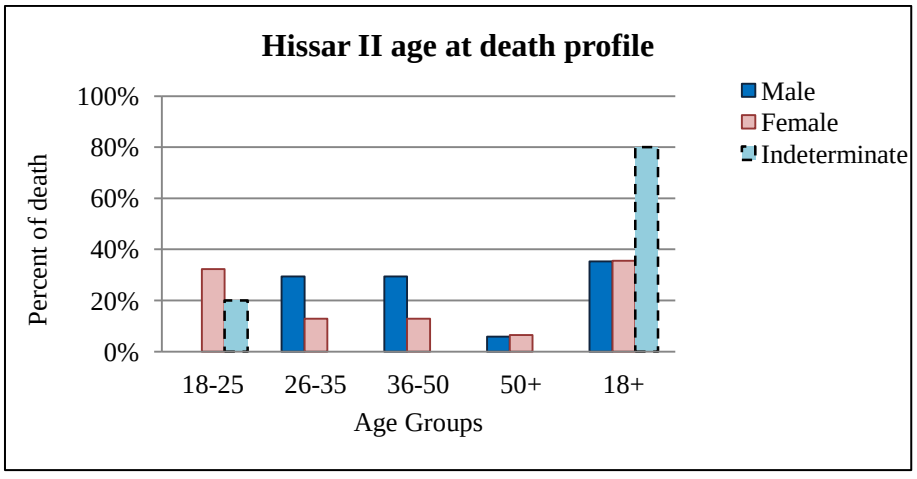


Fig 7.7. Hissar II: Age-at-death distribution by sex

7.2.3. Hissar III

(i) Sex

Table 7.8 and Figure 7.8 illustrate the sex distribution for the skeletons. One-hundred and forty-one of the 287 adults (49.1%) were estimated to be male, 127 were female (44.3%), and 19 (6.6%) were "indeterminate" (significant (X^2=93.185, p=0.000)).

Table 7.8. Hissar III: Sex distribution

Sex distribution	*No.*	*%*
Male	141	49.1%
Female	127	44.3%
Indeterminate	19	6.6%
Total	287	100%

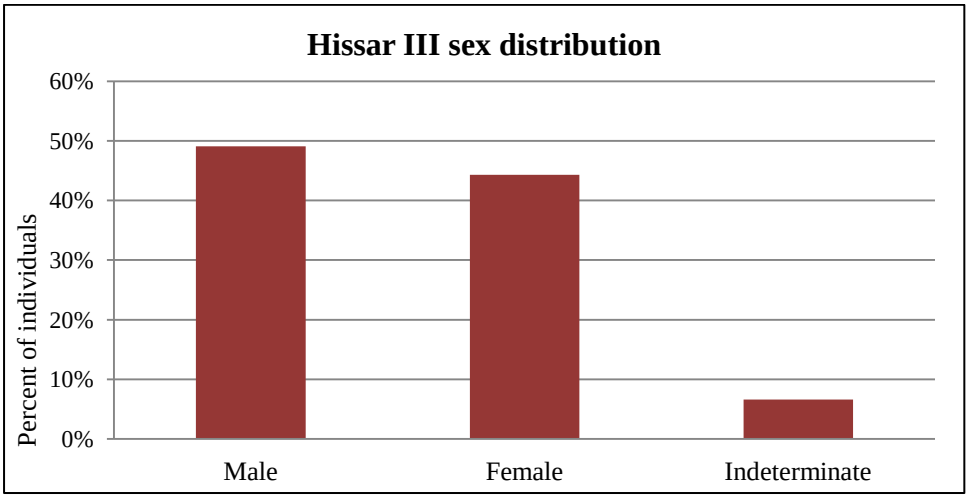


Fig 7.8. Hissar III: Sex distribution (%)

(ii) Age-at-death distribution

The age-at-death distribution can be found in Table 7.9 and Figure 7.9. One-hundred and ninety-six of the 287 adults could be placed in an age-category, but there were 91 (31.7%) adults with unknown age labelled "adult" (AA). There was a significant difference in the age at death distribution among males and females (X^2=20.311, p=0.009). Figure 7.9 shows that in general females between 18 to 35 years old had a higher mortality than males (YA1, YA2). However, in the age-range 36 to 50 years old (MA) and over (OA), males showed higher mortality than females. The total % of YA2 mortality was higher than the other age-groups.

Table 7.9. Hissar III: Age-at-death distribution by sex

		Male		**Female**		**Indeterminate**		**Total**	
Age-category	***Age***	*NO.*	*%*	*NO.*	*%*	*NO.*	*%*	*NO.*	*%*
YA1	18-25	12	8.5%	17	13%	1	5.3%	30	10.5%
YA2	26-35	41	29%	39	30.7%	4	21%	84	29%
MA	36-50	44	31%	30	23.6%	1	5.3%	75	26%
OA	50+	6	4.3%	1	0.8%	0	0%	7	2.4%
AA	18+	38	27%	40	31.5%	13	68%	91	31.7%
Total	-	141	100%	127	100%	19	100%	287	100%

The % of deaths of YA2 individuals increased steadily to 18.8% and was more than for YA1. The percentage of female deaths was 4.9% and 1.6% more than for males

in the YA1 and YA2 age-groups, respectively. The mortality rate was 7.4% more among MA males than females. The death rate was 3.2% less among MA individuals (26.1%) when compared with YA2 (29.3%), and 23.7% less in the OA category compared to MA (Table 7.9). The proportion of OA males was 3.5% more than females of the same age. Among unaged adults, females had the higher % of deaths compared to males of this group (27% V 31.5%).

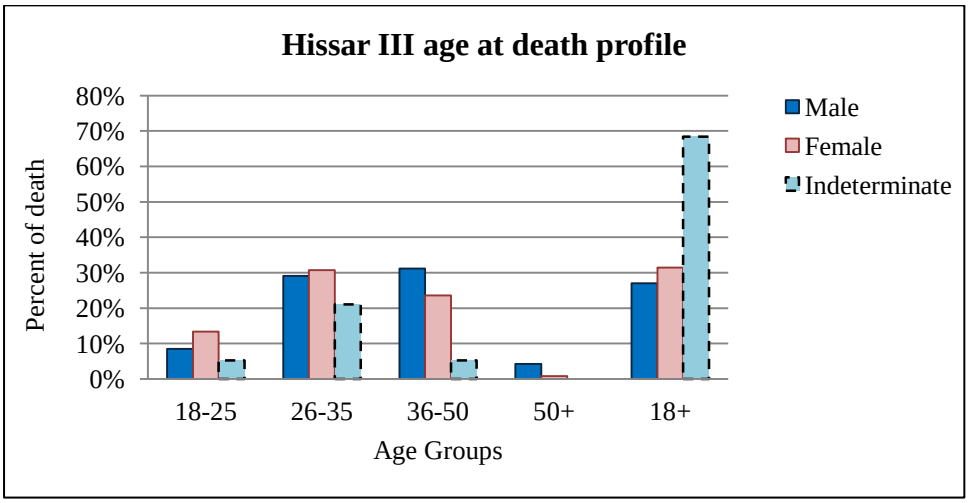


Fig 7.9. Hissar III: Age-at-death distribution by sex

7.3. Metrical Analysis: Normal Variation

The craniofacial and dental metrical analysis of the *Tepe Hissar* individuals produced much interesting data which are presented as follows:

1- Preliminary descriptive statistical analysis of the cranial and dental measurements

2- A multivariate statistical analysis of the cranial and dental measurements

3- Dendrograms and scatter plots to illustrate the data

7.3.1. Craniofacial Metrical Variation

(i) Descriptive Statistical Analysis

There were 133 skulls available for craniometric analysis, two were from Hissar I (1 female, 1 male), 17 were from Hissar II (7 male, 10 female), and 114 from Hissar III (67 males, 47 females). For each of the 133 skulls, 14 measurements on the skull and 10 measurements on the facial skeleton were taken. The means and standard deviations for the craniofacial measurements recorded in males and females from the three periods are

tabulated in Tables 7.10 and 7.11 provide statistically significant differences resulting from ANOVA and compares the individuals by period and sex.

Statistical analyses indicated a significant difference in 9 craniofacial variables (6 cranial and 3 facial) between females and males from Hissar II. The males of this period had larger craniofacial measurements than the females. In contrast, there was no significant difference between one male and one female individual from Hissar I, but the male had larger craniofacial measurements than the female. The males and females from Hissar III demonstrated the greatest difference in measurements. Of 24 craniofacial measurements examined, 18 (10 cranial and 8 facial) were statistically significantly different. Comparison of males from Hissar II and III showed that only "nasal height" exhibited a statistically significant difference (F=4.54, p=0.036), and the males from Hissar III had a greater nasal height (51.7mm) compared to males from Hissar II (48.1mm). On the other hand, comparing females, there were two measurements that showed a significant difference, "bizygomatic breadth" (F=6.94, p=0.011) and "auricular breadth" (F=3.43, p=0.039). The bizygomatic breadth for Hissar II was lower (113.4 mm) than for Hissar I (122.5mm) and Hissar III (117.8mm). The biauricular breadth for Hissar III was the greatest (115mm) compared to Hissar II (108.6 mm) and Hissar I (103mm). However, when comparing the mean craniofacial measurements for the population, together with the sexes pooled, "bizygomatic breadth" (F=6.79, p=0.001) and "auricular breadth" (F=4.164, p=0.018) exhibited statistically significant differences.

Table 7.10. Descriptive statistical analysis for Tepe Hissar craniofacial measurements (mm) by sex and period

	Hissar I				Hissar II				Hissar III			
Code/Variables	Male (n=1)		Female (n=1)		Male (n=7)		Female (n=10)		Male (n=67)		Female (n=47)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Neurocranium												
1-Maximum Cranial Length	200	-	176	-	192.6	9.84	180	3.82	188.5	6.59	181.8	5.26
2-Maximum Cranial Breadth	131	-	131	-	133.4	3.95	132.2	4.75	134.7	5.17	132.8	4.78
4-Basion-Bregma Height	-	-	-	-	135	4.47	131	6.05	135.4	5.57	130.2	4.98
5-Cranial Base Length	-	-	-	-	103.9	5.27	97.9	2.88	102.6	4.21	98.5	4.05
9-Biauricular Breadth	-	-	103	-	115.2	3.12	108.6	4.92	115.9	5.32	115	4.14
19-Frontal Chord	117	-	113	-	115.9	1.21	110.7	5.71	112.8	4.89	110.4	5.06
20-Parietal Chord	123	-	105	-	117.5	14.65	114.5	4.35	117.5	5.19	114.6	6.34
21-Occipital Chord	97	-	101	-	100.7	5.85	94.4	4.5	98.6	4.65	97.1	5.09
22-Foramen Magnum Length	-	-	-	-	35.4	2.48	34.7	1.42	36.3	2.65	34.6	2.29
23-Foramen Magnum Breadth	-	-	-	-	28.2	1.84	27.3	1.76	29.7	2.18	30.7	11.3
24-Mastoid Length	37	-	24.8	-	31.9	4.97	29	1.2	32.3	3.4	28.8	2.98
S1-Frontal Arc	130	-	130	-	133.1	5.69	127.8	6.49	129.4	7.04	127.1	6.67
S2-Parietal Arc	144	-	113	-	131.2	15.97	129.2	6.94	131.8	6.5	128.8	6.88
S3-Occipital Arc	115	-	115	-	124	10.41	114	6.98	119.3	6.76	116.3	7.26
Facial Skeleton												
3-Bizygomatic Diameter	123.7	-	122.5	-	123.7	6.02	113.4	5.5	124.3	5.88	117.8	4.57
10-Upper Facial Height	-	-	67	-	66.7	8.53	67.8	4.79	70.4	6.76	66.6	3.99
11-Minimum Frontal Breadth	94	-	90	-	94.4	5.31	91	2.58	94.5	4.38	92.3	4.04
12-Upper Facial Breadth	107	-	96	-	102.9	3.93	97.7	2	103.7	3.65	99.3	3.71
13-Nasal Height	-	-	-	-	48.1	8.961	51.8	6.81	51.7	3.43	50.2	4.69
14-Nasal Breadth	-	-	-	-	24.5	1.75	23.6	1.38	25.5	2.16	24.4	2.43
15-Orbital Breadth	35.9	-	36.7	-	38	1.78	38.5	7.31	38.6	1.88	36.8	2.4
16-Orbital Height	-	-	30.5	-	31.7	2.47	31.2	1.65	32	1.54	32.1	2.19
17-Biorbital Breadth	96	-	90.6	-	94.3	4.35	90.5	1.89	95.4	2.97	91.8	3.85
18-Interorbital Breadth	-	-	19.9	-	21.5	2.18	20.2	1.62	21.6	2.11	20.4	2.36

Table 7.11. Statistically significant differences in craniofacial measurements among the Tepe Hissar population

*code**	*1*	*2*	*4*	*5*	*9*	*19*	*20*	*21*	*22*	*23*	*24*	*S1*	*S2*	*S3*	*3*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
Hissar I: Comparison of mean craniofacial measurements- by sex																								
F																								
Sig.																								
Hissar II: Comparison of mean craniofacial measurements- by sex																								
F	***12.1***	*.311*	*2.20*	***9.07***	***8.47***	***5.42***	*.380*	***5.82***	*.490*	*.848*	*3.17*	*3.07*	*.199*	***5.27***	***12.2***	*.118*	*3.16*	***12.7***	*.946*	*1.27*	*.280*	*.235*	**6.19**	1.65
Sig.	**.003**	*.581*	*.192*	**.009**	**.011**	**.032**	*.548*	**.032**	*.496*	*.373*	*.097*	*.100*	.662	**.036**	**.004**	*.736*	*.096*	**.003**	*.346*	*.278*	*.870*	*.69*	**.025**	.221
Hissar III: Comparison of mean craniofacial measurements- by sex																								
F	**33.3**	3.90	**23.4**	**24.2**	**2.07**	**6.15**	**6.85**	2.49	**11.68**	.444	**29.12**	3.01	**5.42**	**5.16**	**36.9**	**11.76**	**7.68**	**37.1**	3.86	**5.633**	**1.37**	.019	**23.3**	**6.84**
Sig.	**.000**	.06	**.000**	**.000**	**.000**	**.015**	**.01**	.118	**.014**	.507	**.000**	.86	**.022**	**.025**	**.000**	**.001**	**.007**	**.000**	.06	**.024**	**.000**	.891	**.000**	**.012**
Comparison of mean craniofacial measurements for males																								
F	2.36	.449	.32	.534	.101	1.69	.371	.585	.712	2.55	1.03	.921	1.230	1.67	.069	1.82	.009	.576	**4.5**	.601	1.23	.226	.254	.006
Sig.	.102	.640	.859	.467	.752	.191	.691	.560	.402	.115	.362	.403	.298	.195	.793	.180	.991	.565	**.036**	.551	.298	.636	.776	.937
Comparison of mean craniofacial measurements for females																								
F	.785	.135	.170	.179	**3.46**	.129	1.237	1.58	.009	.883	1.091	.127	2.62	.252	**6.94**	.340	.612	1.29	.879	.810	.875	.884	.594	.041
Sig.	.461	.874	.682	.674	**.039**	.880	.298	.216	.925	.352	.343	.881	.082	.778	**.011**	.713	.546	.281	.353	.373	.423	.419	.556	.960
Comparison of mean craniofacial measurements for all periods at *Tepe Hissar*, sexes- by pooled																								
F	.096	.760	.127	.188	**4.16**	.666	.195	.480	.921	1.71	.287	.405	.079	.196	**6.79**	.498	.680	1.73	.387	1.56	.468	1.14	1.46	.272
Sig.	.909	.470	.722	.665	**.018**	.516	.823	.620	.339	.193	.751	.668	.924	.822	**.015**	.609	.509	.181	.535	.214	.628	.325	.235	.762

P≤0.05, the shade cells show the differences were statistically significant, * see Table 7.10/ variable codes.

(ii) Multivariate Statistical Analysis of Craniofacial Measurements

The results of two multivariate statistical procedures, Mahalanobis generalised distances (d^2), and principal component analysis (PCA), as well as the resulting cluster analyses and scatter plots included a comparison of craniofacial variation in individuals within periods by sex, a comparison of craniofacial variation in individuals between periods by sex, and a comparison of craniofacial variation between males and females at *Tepe Hissar* by period.

(a) Comparisons of craniofacial variation of individuals within each period by sex

Mahalanobis generalised distances (d^2)

Mahalanobis generalised distances (d^2) were derived from 14 cranial and 10 facial skeleton measurements common to 131 adult male and female crania representing the Chalcolithic and Bronze Age population of *Tepe Hissar*. Applying the Ward method (Ward, 1963) and Euclidean distances clustering algorithm resulted in a dendrogram for each period which are presented in following sections.

Hissar I

A male and a female skull were available from Hissar I for craniofacial metrical study. The male skull was not considered in multivariate statistical analysis because it was not complete enough for this analysis, but the female skull was used in PCA where females from *Tepe Hissar* were compared craniometrically.

Hissar II

Tables 7.12 and 7.13 show the Mahalanobis distances (d^2) between seven males and 10 females from Hissar II, respectively. Table 7.12 shows that the smallest distances were between males A200 and B36, as well as between males B23 and A32 in this period. Males B33 and A218 showed small distances between each other, but male A49 showed a larger distance from other males.

Table 7.12. Craniofacial Mahalanobis distances (d2) for 7 males from Hissar II

	A32	B36	B23	A200	A49	A218	B33
A32	0						
B36	6.664	0					
B23	1.804	4.86	0				
A200	5.186	1.478	3.382	0			
A49	19.096	12.432	17.292	13.91	0		
A218	27.931	21.267	26.127	22.745	8.835	0	
B33	28.459	21.796	26.656	23.273	9.363	0.528	0

Figure 7.10 shows two distinct clusters (D1,D2). The first contains individuals B33 and A218 closely related to each other, and secondarily clustered with individual A49. The second (D2) includes individuals A200 and B36, who were secondarily clustered with males A32 and B23 from this cluster.

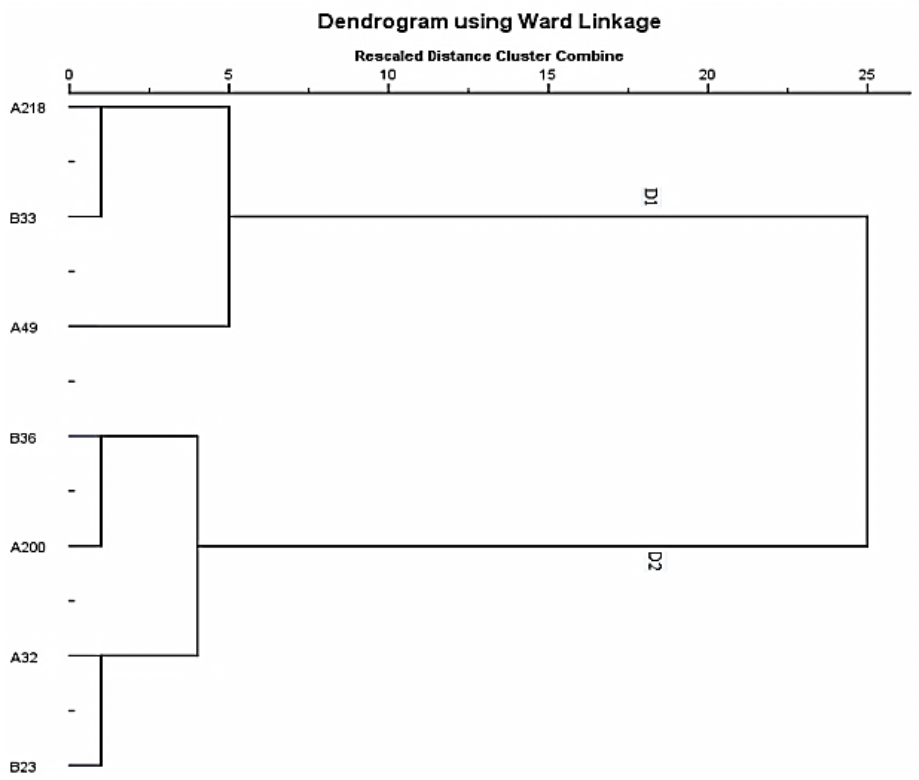


Fig 7.10. Dendrogram of biological relationships of males from Hissar II based on cluster analysis of Mahalanobis generalised distances (d2)

Table 7.13 shows that the smallest biological distances were between females A42, B22, A128, B30 and B18 as well as between B28 and B17. Females B26, B19, and B24 showed larger distances from other females in this period.

Table 7.13. Craniofacial Mahalanobis distances (d2) for 10 females from Hissar II

	A128	B22	A42	B30	B17	B28	B18	B24	B19	B26
A128	0									
B22	2.483	0								
A42	1.780	0.703	0							
B30	4.197	1.714	2.417	0						
B17	13.890	11.407	12.110	9.693	0					
B28	13.052	10.569	11.272	8.855	0.838	0				
B18	5.897	3.414	4.116	1.700	7.994	7.156	0			
B24	22.085	19.602	20.304	17.888	8.194	9.033	16.188	0		
B19	35.184	32.701	33.404	30.987	21.294	22.132	29.287	13.099	0	
B26	79.284	76.801	77.504	75.087	65.394	66.232	73.387	57.199	44.100	0

Figure 7.11 shows a dendrogram of the Mahalanobis generalized distances (d^2) between females from Hissar II. The females formed two separate clusters labelled D1 and D2. The first (D1) contains all but one of the individuals. It is divided into two

distinct separate sub-clusters, A and B. The second cluster (D2) with one individual (B26) was the most isolated in this diagram. Cluster A contains five individuals that showed close similarities to each other. In cluster B, individuals B17 and B28 showed close biological affinity, but they were separated from females B24 and B19.

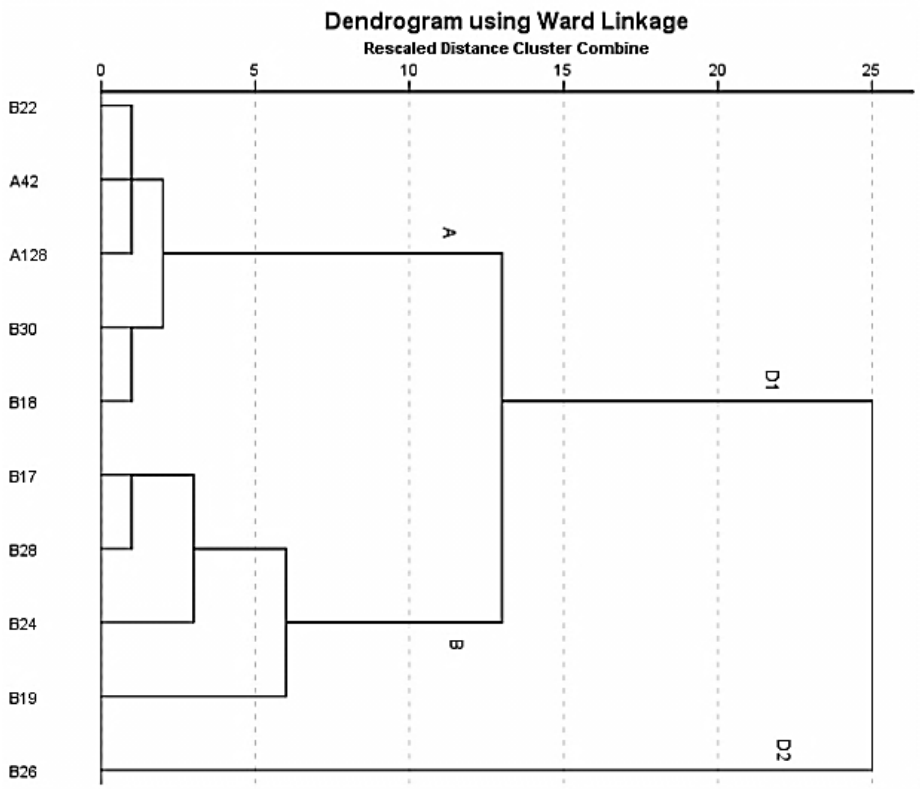


Fig 7.11. Dendrogram of biological relationships of females from Hissar II based on cluster analysis of Mahalanobis generalised distances (d2**)**

Hissar III

The biological distances between the males were small, but male A168 showed the largest distance compared to the rest of males. Figure 7.12 shows two major distinct clusters (D1, D2). The first cluster (D1) is divided into two distinct sub-clusters (A and B), which then are divided into other smaller clusters containing individuals with close similarities to each other. The second cluster (D2) is also subdivided into two distinct sub-clusters (C and O) and smaller clusters. Figure 7.12 shows that the males from Hissar III divided into several small groups with evidence of biological affinity within each group, but with distinct dissimilarity from the neighbouring groups in this cluster.

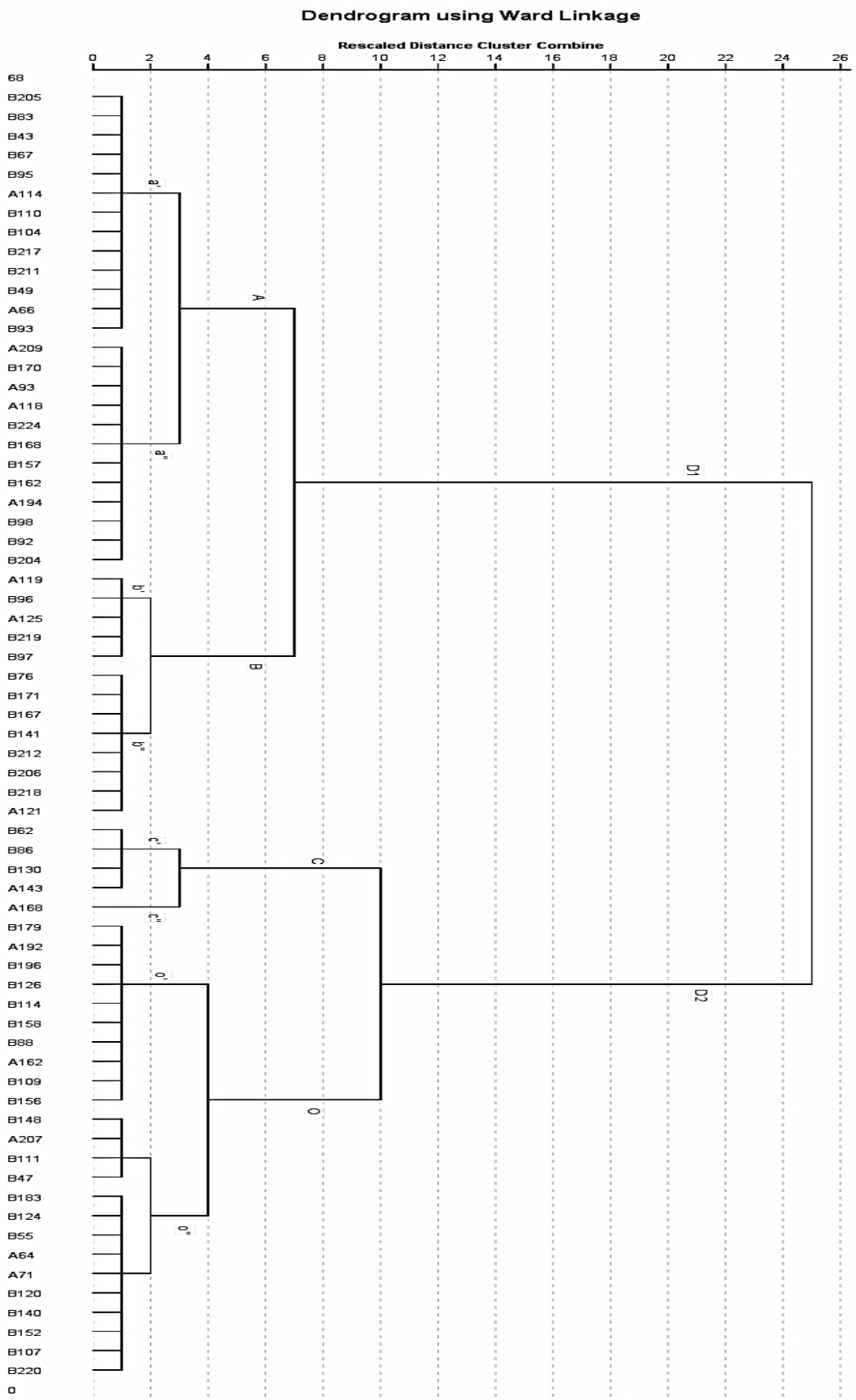


Fig 7.12. Dendrogram of biological relationships of males from Hissar III based on cluster analysis of Mahalanobis generalised distances (d2)

Figure 7.13 compares biological distances between females from Hissar III. The females formed two distinct clusters (D1 and D2). The first cluster (D1) contained almost all the individuals and was divided into two sub-clusters A and B. The second cluster (D2) was the most isolated and females A205, A141, B131, and B197 showed the largest difference among this group. In sub-cluster C in D2, females B131 and B197 were related but separated from A141. Cluster O of D2 was the most isolated (female A205). Group A formed two distinctive smaller sub-clusters (a′,a″) which contained five separate smaller groups with evidence of within group similarity. The females in sub-cluster B also divided into three separate smaller groups with patterns of biological affinity within each group. Figure 7.13 shows that the females divided into several small groups, with evidence of affinity within each group, but clear separation from those individuals from the neighbouring groups in this cluster.

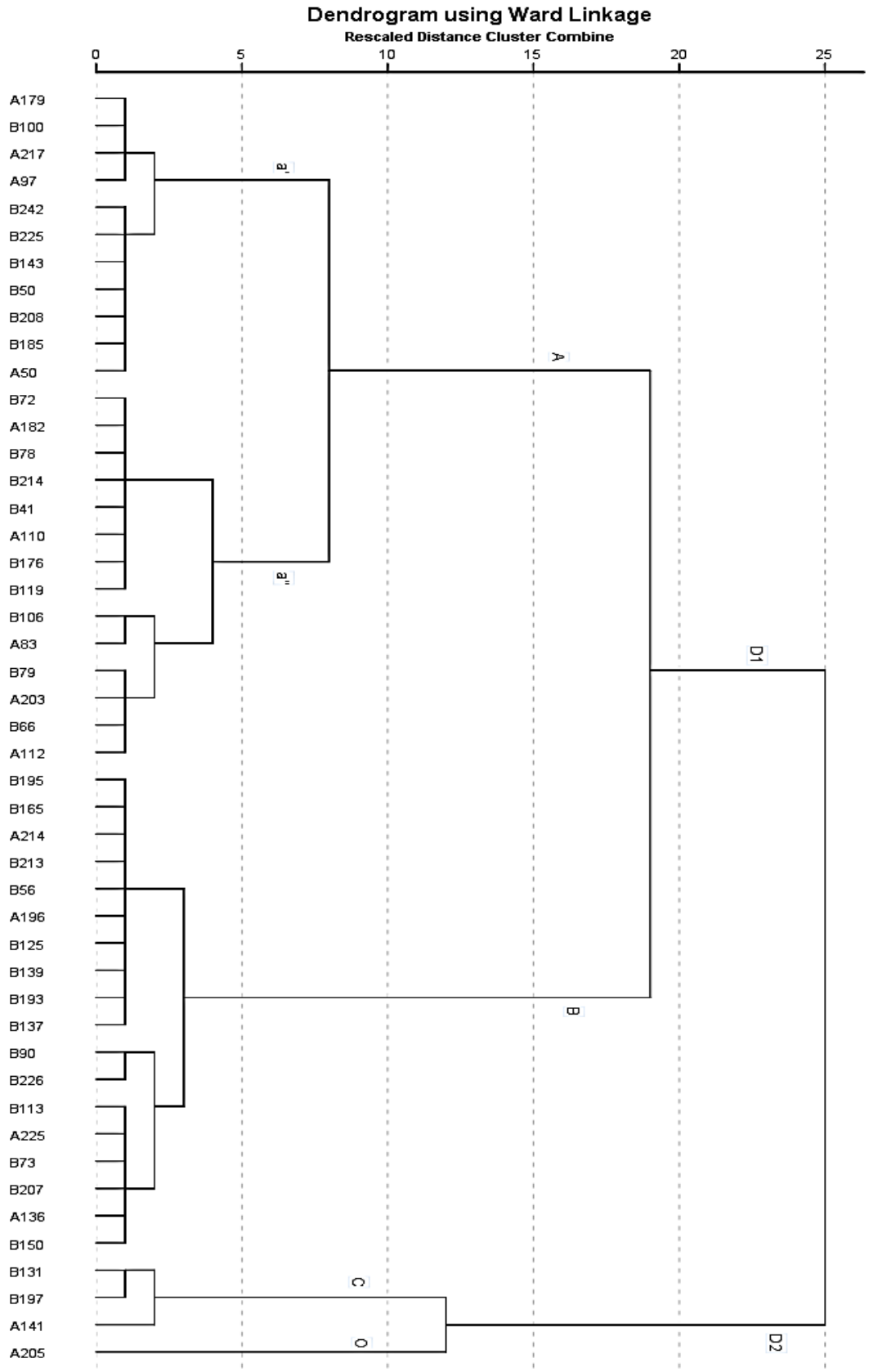


Fig 7.13. Dendrogram of biological relationships of females from Hissar III based on cluster analysis of Mahalanobis generalised distances (d2)

Principal component analyses (PCA)

PCA were determined from 14 cranial and 10 facial skeleton measurements common to 132 individuals. Six components which had Eigenvalues greater than 1.0 were extracted from the within-individual matrix. Together these six components explain 78.8% of the total variance. The results of the varimax rotated PCA and Eigenvalues for each factor are presented in Table 7.14. It is suggested that the most important variables in the first component (PC1) were bizygomatic breadth, upper facial breadth, biorbital breadth, biauricular breadth, minimum frontal breadth and cranial base length, and for the second component (PC2) the parietal arc and parietal chord were most responsible for producing group separation. The first two components explain 47% of total variance (PC1=33.5%, PC2=13.4%). Scatter plots were generated for these two components (Figures 7.14-17).

Table 7.14. Principal component loadings after varamix rotation for 24 craniofacial measurements for 132 individuals

Code	Variable	PC1	PC2	PC3	PC4	PC5	PC6
3	*Bizygomatic Breadth*	0.904	0.089	0.019	0.066	0.191	-0.019
12	*Upper Facial Breadth*	0.888	0.126	0.104	0.028	0.03	0.055
17	*Biorbital Breadth*	0.805	0.051	0.057	0.015	0.109	0.067
9	*Biauricular Breadth*	0.736	0.014	0.121	0.098	0.143	-0.402
11	*Minimum Frontal Breadth*	0.680	0.092	0.287	-0.031	-0.063	0.049
5	*Cranial Base Length*	0.624	0.269	0.025	0.182	0.298	0.144
18	*Interorbital Breadth*	0.497	0.153	0.217	0.019	-0.066	-0.001
24	*Mastoid Length*	0.463	0.040	0.218	0.147	0.225	0.078
15	*Orbital Breadth*	0.427	0.015	0.088	-0.067	0.243	0.118
14	*Nasal Breadth*	0.249	0.212	0.073	0.002	0.023	0.051
S2	*Parietal Arc*	0.038	0.958	0.02	-0.093	0.116	-0.051
20	*Parietal Chord*	0.109	0.933	0.159	-0.005	0.04	-0.077
1	*Max Cranial Length*	0.499	0.519	0.312	0.472	0.076	0.061
22	*Foramen Magnum Length*	0.232	0.287	0.067	0.123	0.088	0.06
S1	*Frontal Arc*	0.130	0.177	0.936	0.109	0.12	0.009
19	*Frontal chord*	0.253	0.122	0.842	0.169	0.229	0.107
8	*Max cranial breadth*	0.394	0.048	0.517	0.057	0.210	-0.169
S3	*Occipital Arc*	0.104	-0.013	0.145	0.955	-0.067	-0.099
21	*Occipital Chord*	-0.024	0.016	0.071	0.918	0.087	0.002
10	*Upper Facial Height*	0.215	0.069	0.064	0.111	0.873	-0.067
13	*Nasal Height*	-0.021	0.085	0.117	0.002	0.773	-0.024
4	*Basion- Bregma Height*	0.228	0.4	0.378	0.274	0.434	0.084
16	*Orbital Height*	0.157	0.048	0.173	-0.08	0.329	0.083
23	*Foramen Magnum Breadth*	0.132	-0.031	0.034	-0.055	0.031	0.938
Eigenvalue		216.007	86.574	72.507	52.038	42.446	37.754
Percent of Variance		33.54	13.44	11.257	8.079	6.606	5.862
Percent of Cumulative		33.54	46.97	58.23	66.31	72.92	78.78

Hissar II

Figure 7.14 provides a two dimensional scatter plot of biological distances between the individuals from Hissar II on the first and second component scores. The closest associations were between females A42, B28, B33, B18, and B17. There was close affinity between female B26 and male A32, as well as between female A128 and male B36. However, males A200 and A218 were isolated from the other males and females. Male A49 separated from the other males, as well as female B24 from the rest of females. This pattern matches the dendrograms from this period.

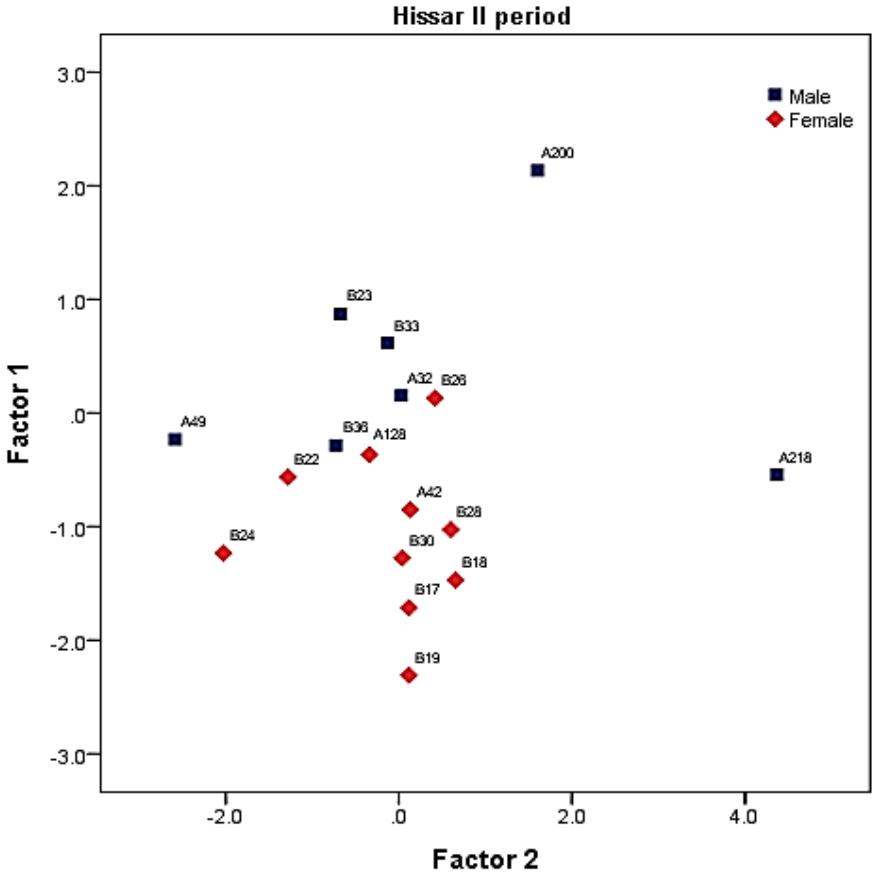


Fig 7.14. Scatter plot comparing distance among 17 individuals (females and males) from Hissar II based on factor scores generated from PCA of 24 craniofacial measurements

Hissar III

Figure 7.15 shows the scatter plot of biological distances between individuals from Hissar III based on the first and second principal component factors. The plot shows a distinct separation between males and females. However, particularly in the centre of this plot, there is overlap among some individuals which illustrates closer biological affinity. Among males, some were close to each other and some, for example B207, B124, B152, and A192, were located a long distance from the rest of the males.

Among females there was also some close similarity while for some, for example A110, A214, and A185, there was a greater distance from the rest of the females. This pattern matches the dendrograms from this period.

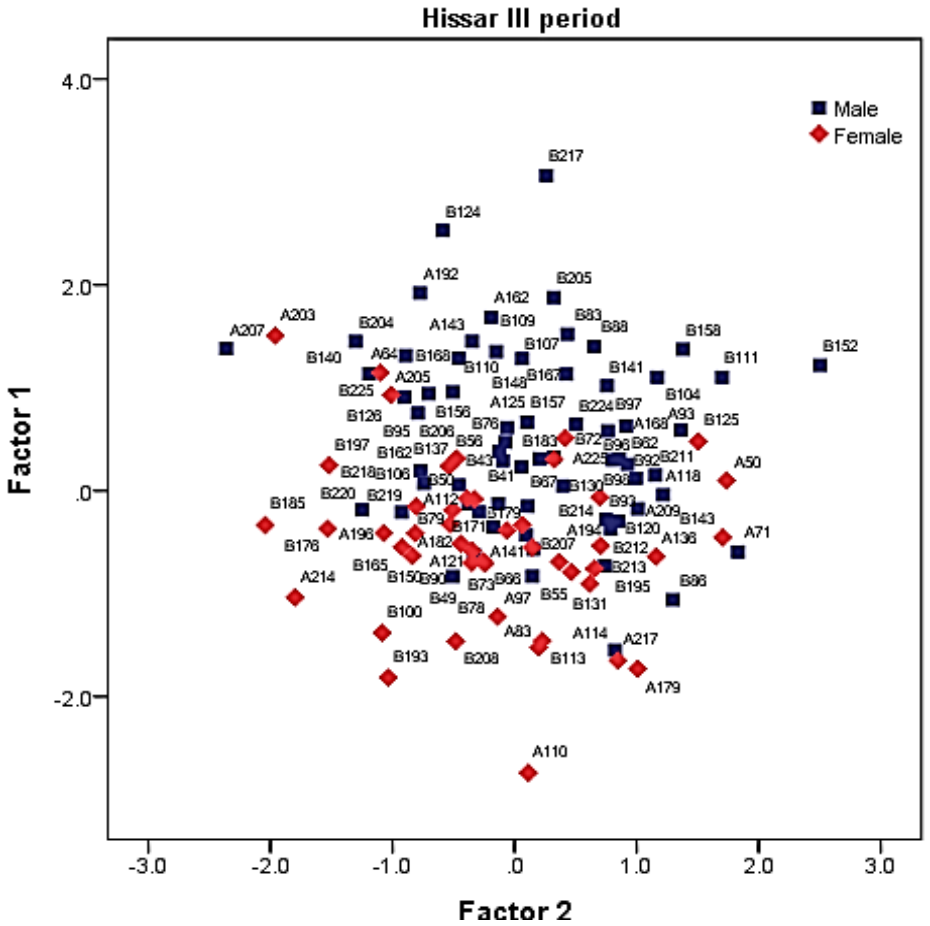


Fig 7.15. Scatter plot comparing distance among 114 individuals (females and males) from Hissar III based on factor scores generated from PCA of 24 craniofacial measurements

(b) Comparison of craniofacial variation in individuals between periods, by sex

Figure 7.16 shows biological affinities between the males from Hissar II and III. The males from Hissar II were less similar to each other, while individually they showed a closer connection to some males from Hissar III. Of seven males from Hissar II, 4 were placed close to males from Hissar III, showing craniometrical similarity. However, individuals A218, A200, and A49 were isolated and separated from the rest of the males from Hissar II and Hissar III. Among the individuals from Hissar III, B217, B152, A71, B86, A114, A207, A192 and B124 were further away in distance from the other males of this period, as well as from males from Hissar II.

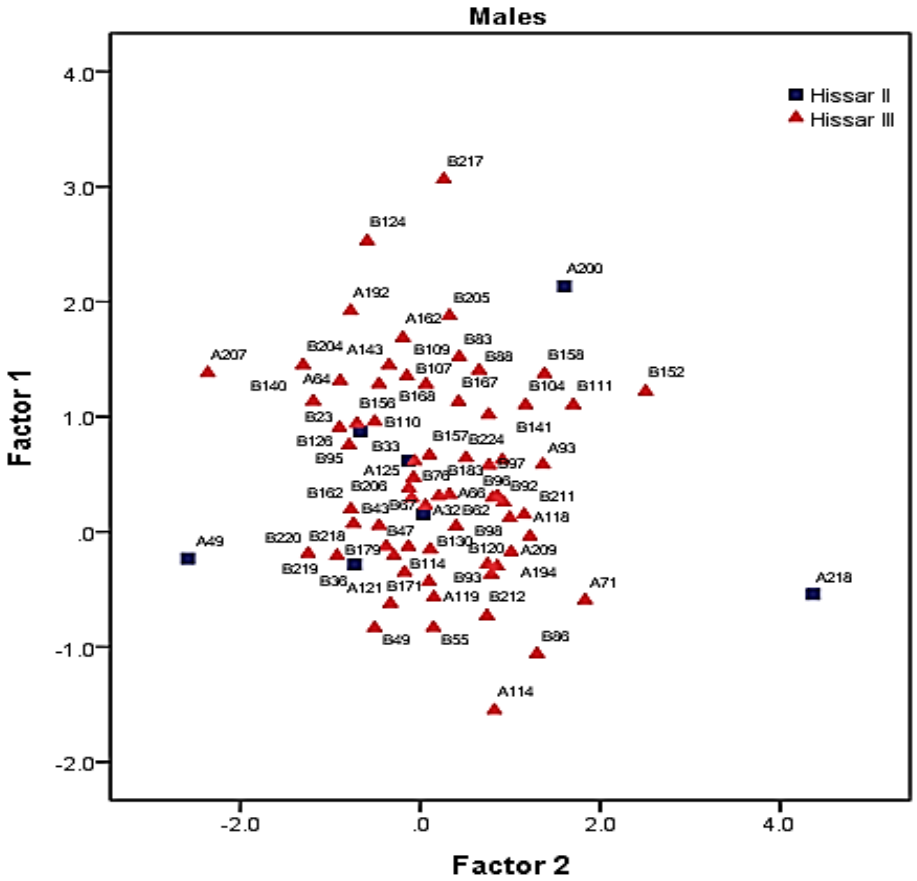


Fig 7.16. Scatter plot comparing distance among 74 males from Hissar II and III based on factor scores generated from PCA of 24 craniofacial measurements

Figure 7.17 shows biological affinities between the females in different periods at *Tepe Hissar*. The only female available from Hissar I (B7) showed biological affinity with one female (B24) from Hissar II. The females from Hissar II showed less similarity to each other, while individually showing approximate biological similarity to some females from Hissar III. The females from Hissar III were closely affiliated to each other but, some females were well away from the centre of the plot. For example, individual A203 was isolated, and B125, A50, B143, A136, B193, B100, and B197 were separated from each other and from other females.

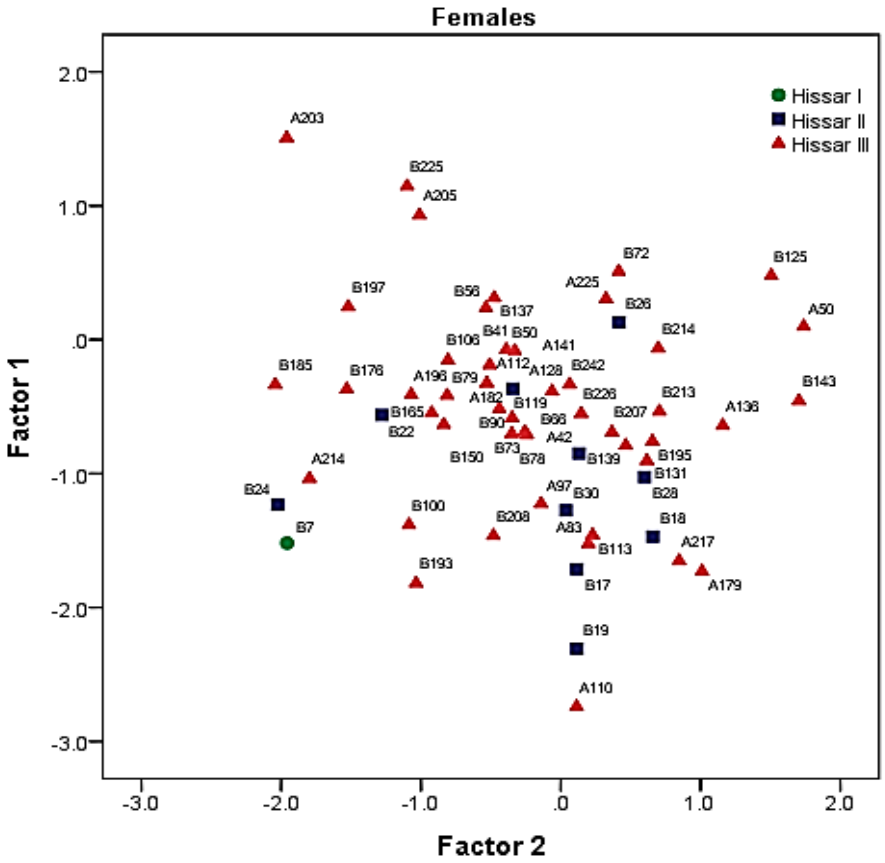


Fig 7.17. Scatter plot comparing distance among 58 females from Hissar I, II and III based on factor scores generated from PCA of 24 craniofacial measurements

(c) Comparison of craniofacial variation between males and females at *Tepe Hissar* by period

PCA was applied to the means of 14 cranial and 10 facial skeletal measurements (Table 7.15) in 57 females and 74 males.

Table 7.15. Descriptive statistical analysis of mean craniofacial measurements (mm) of 57 females and 74 males from Hissar II and Hissar III

Code/Variables	Male		Female	
	Mean	*SD*	*Mean*	*SD*
Neurocranium				
1-Maximum Cranial Length	190.54	2.871	181.32	0.728
2-Maximum Cranial Breadth	134.08	0.912	132.52	0.445
4-Basion-Bregma Height	135.15	0.212	130.72	0.403
5-Cranial Base Length	103.29	0.806	98.17	0.382
9-Biauricular Breadth	115.83	0.269	112.9	6.081
19-Frontal Chord	114.38	2.093	110.57	0.191
20-Parietal Chord	117.23	0.24	114.57	0.099
21-Occipital Chord	99.43	1.103	95.78	1.945
22-Foramen Magnum Length	35.85	0.686	34.69	0.007
23-Foramen Magnum Breadth	29.05	0.898	28.94	2.277
24-Mastoid Length	32.03	0.311	28.9	0.205
S1-Frontal Arc	131.27	2.645	127.47	0.474
S2-Parietal Arc	131.74	0.035	129.01	0.276
S3-Occipital Arc	121.71	3.444	115.38	1.245
Facial Skeleton				
3-Bizygomatic Diameter	123.94	0.629	115.45	2.899
10-Upper Facial Height	68.57	2.638	67.21	0.856
11-Minimum Frontal Breadth	94.49	0.078	91.65	0.919
12-Upper Facial Breadth	103.27	0.58	98.56	1.209
13-Nasal Height	49.9	2.503	51.01	1.174
14-Nasal Breadth	24.98	0.622	24.06	0.559
15-Orbital Breadth	38.23	0.474	37.62	1.216
16-Orbital Height	31.91	0.24	31.67	0.58
17-Biorbital Breadth	95.38	1.485	91.17	0.94
18-Interorbital Breadth	21.45	0.035	20.27	0.163

Three components were extracted from the within-individual matrix which had Eigenvalues greater than 1.0. Together these three components explain 100% of the total variance. The results for varimax rotated PCA and Eigenvalues for each factor are presented in Table 7.16. The most important variables in the first component (PC1) were frontal arc and chord, occipital arc and chord, maximum cranial length, cranial base length, interorbital breadth, parietal arc and chord, basion-bregma height, minimum frontal breadth, mastoid length, bizygomatic breadth, and upper facial breadth. In the second component (PC2) it was the upper facial height, foramen magnum length, maximum cranial breadth and orbital breadth that were most responsible for producing group separation. The first two components explain 92.07% of total variance (PC1=81.2%, PC2=10.9%). A scatter plot was generated from these two components to evaluate affinities between males and females from Hissar II and III (Figure 7.18).

Table 7.16. Principal components loadings after varamix rotation for the means of 24 craniofacial measurements for 131 individuals from Hissar II and III

Code	Variable	PC1	PC2	PC3
19	*Frontal Chord*	.997	.046	-.058
S1	*Frontal Arc*	.989	-.039	-.143
S3	*Occipital Arc*	.989	-.012	.149
1	*Maximum Cranial Length*	.973	.202	.113
5	*Cranial Base Length*	.930	.335	.151
21	*Occipital Chord*	.877	.078	.474
18	*Interorbital Breadth*	.873	.423	.244
S2	*Parietal Arc*	.849	.527	.029
4	*Basion-Bregma Height*	.832	.553	.047
11	*Minimum Frontal Breadth*	.815	.401	.419
20	*Parietal Chord*	.814	.552	.180
24	*Mastoid Length*	.805	.587	.084
3	*Bizygomatic Diameter*	.787	.430	.443
12	*Upper Facial Breadth*	.776	.500	.384
13	*Nasal Height*	-.755	.621	-.209
10	*Upper Facial Height*	-.058	.998	.006
22	*Foramen Magnum Length*	.486	.843	.230
2	*Maximum Cranial Breadth*	.482	.748	.457
15	*Orbital Breadth*	.176	.716	-.675
17	*Biorbital Breadth*	.637	.663	.393
14	*Nasal Breadth*	.399	.649	.648
23	*Foramen magnum breadth*	-.125	.061	.990
16	*Orbital Height*	.149	.227	.963
9	*Biauricular Breadth*	.376	-.008	.926
	Eigenvalue	133.49	17.88	13.04
	Percent of Variance	81.2	10.88	7.93
	Percent of Cumulative	81.2	92.07	100

Figure 7.18 shows a large distance between females and males for both periods, no close affinities being seen between males from both periods. However, the females were closer to each other when compared to the males, but distanced from the males.

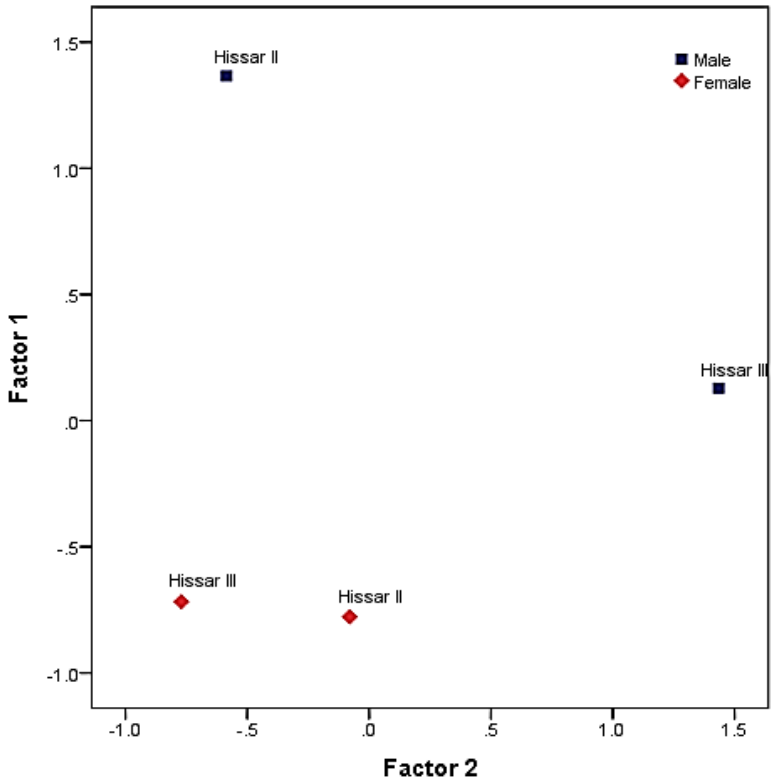


Fig 7.18. Scatter plot comparing distance among females and males from Hissar II and III based on the factor scores generated from PCA of the means of 24 craniofacial measurements

7.3.2. Dental Metrical Variation

(i) Descriptive Statistical Analysis of Dental Measurements

Data from statistical analyses (ANOVA) of the dental measurements for the *Tepe Hissar* population are presented independently for males and females for the three periods (Tables 7.17 and 7.18). Table 7.17 shows the means, standard deviations and sample sizes for MD (mesiodistal) and BL (buccolingual) crown diameters (total mandibles=84, total maxillae=59) for males from the three periods.

Table 7.17. Male MD and BL crown diameters (mm), by period

Tooth	Hissar I			Hissar II			Hissar III		
	N	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*
Mesiodistal diameters (mm)									
UI1	4	8.3	7.27	2	8.1	8.48	10	8.1	6.96
UI2	3	7.0	4.04	2	6.7	3.53	10	6.6	4.69
UC	5	7.3	6.7	4	7.4	3.4	21	7.6	7.69
UPM1	5	7.2	5.6	4	6.8	5.03	23	6.9	6.15
UPM2	5	6.7	6.84	5	6.8	5.22	26	6.8	8.74
UM1	5	10.6	8.51	7	10.1	4.39	36	10.0	8.89
UM2	3	9.3	6.55	8	9.9	5.49	36	9.8	8.68
UM3	4	9.1	4.03	6	9.3	10.15	31	9.2	7.47
LI1	5	4.8	9.42	4	5.4	4.46	26	5.0	6.08
LI2	7	5.2	6.63	4	5.8	2.63	38	5.6	7.08
LC	8	6.6	6.5	6	6.9	6.79	47	6.6	6.28
LPM1	7	6.8	3.99	5	7.1	7.15	55	6.6	5.24
LPM2	8	6.9	2.17	4	7.7	12.1	54	6.9	4.75
LM1	8	10.9	8.0	6	10.2	4.89	53	10.9	6.09
LM2	9	10.7	6.04	6	10.4	7.08	61	10.5	6.62
LM3	7	10.7	9.9	6	10.9	9.05	54	10.4	7.5
Buccolingual diameters (mm)									
UI1	4	7.6	3.69	2	7.6	7.78	11	6.7	4.91
UI2	9	7.0	2.52	2	7.6	8.48	11	6.4	4.8
UC	5	8.5	8.17	4	8.5	7.54	23	7.9	5.53
UPM1	5	9.6	8.38	4	9.2	7.14	23	9.1	4.94
UPm2	5	9.8	6.7	5	9.5	10.11	26	9.2	9.32
UM1	4	11.8	7.5	7	11.7	9.12	35	11.3	9.46
UM2	3	11.1	4.72	8	11.7	9.58	36	11.3	7.94
UM3	4	11.7	4.65	6	10.9	13.66	31	10.8	8.29
LI1	5	6.1	3.65	4	6.4	0.96	26	5.8	4.24
LI2	7	6.5	3.63	4	6.5	3.56	39	6.2	5.21
LC	8	7.9	7.39	6	7.7	6.6	46	7.5	7.3
LPM1	7	7.9	7.74	5	7.9	5.67	55	7.7	6.29
LPM2	8	8.5	6.72	4	8.6	14.3	54	8.2	7.27
LM1	8	10.7	6.92	6	10.7	5.95	53	10.6	4.78
LM2	9	10.4	6.84	6	10.4	2.8	61	10.4	5.47
LM3	7	9.7	7.33	6	10.3	8.87	54	9.9	6.55

U=upper (maxillary), L=lower (mandibular), I=incisor, C=canine, PM=premolar, M=molar

A comparison of crown dimension variation between females and males for each period (Table 7.17) showed a significant difference in the size of UM2BL (F=11.97, *p*=0.041) between males and females from Hissar I. There was a significant difference in the size of two maxillary (UPM2MD- F=5.383, *p*=0.041; UM3MD- F=6.33, *p*=0.029) and four mandibular (LI1BL- F=29.37, *p*=0.006; LI2BL- F=7.161, *p*=0.05; LCBL- F=5.656, *p*=0.0.045; LM2BL- F=13.30, *p*=0.004) dental crown dimensions (6/32 total mandibular and maxillary tooth dimensions) between females and males from Hissar II. The teeth were larger in males. However, the males and females from Hissar III showed a significant difference in size for only two teeth (2/32): the BL length of UI1 (F=10.96, *p*=0.003) and LM2 (F=9.38, *p*=0.003).

Figures 7.19 and 7.20 compare the differences in MD and BL size for maxillary and mandibular teeth in males. The MD dimensions of almost all maxillary teeth were identical in Hissar II and III, but for Hissar III the mandidular teeth were identical to Hissar I. The BL dimension for the majority of the maxillary and mandibular teeth was slightly smaller for Hissar III compared to Hissar II and I. Univariate statistical analysis indicated a significant difference in diameters of UI1BL (F=7.027, *p*=0.008), UI2BL (F=6.142, *p*=0.013), UCBL (F=3.303, *p*=0.05), LI1BL (F=3.94, *p*=0.03), and LPM2MD (F=4.619, *p*=0.013) in males. The UI1BL (6.7mm), UI2BL (6.4mm), UCBL (7.9mm), and LI1BL (5.8mm) diameters were smaller for Hissar III compared to Hissar II and I. The MD dimension of LPM2 was larger for Hissar II (7.7mm) compared to Hissar I (6.9mm) and Hissar III (6.9mm).

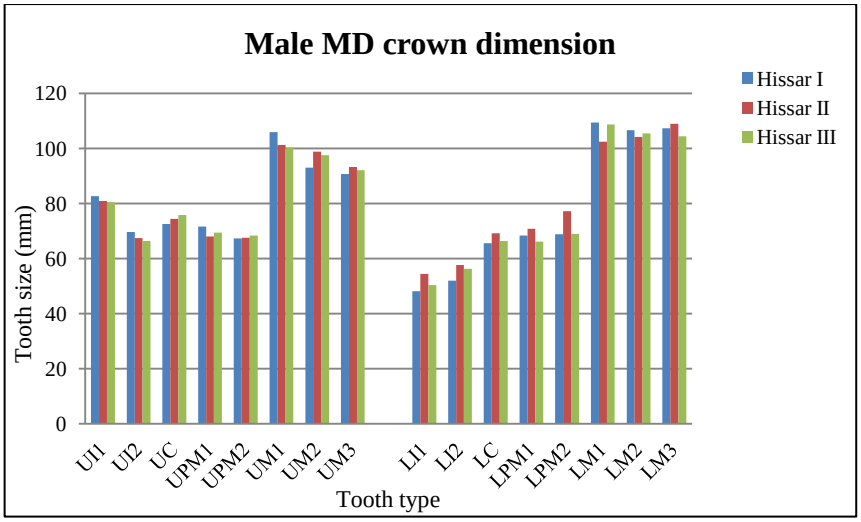


Fig 7.19. Male MD maxillary and mandibular crown size, by period

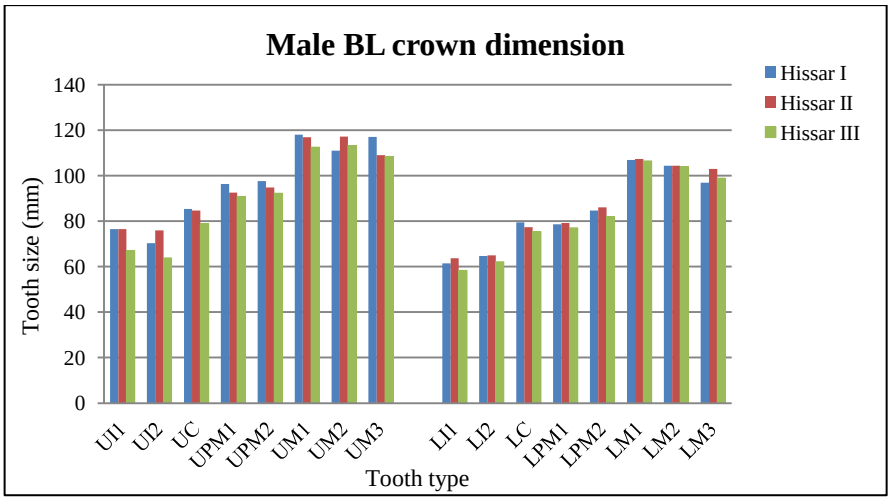


Fig 7.20. Male BL maxillary and mandibular crown size, by period

Table 7.18 presents the means, standard deviations and sample sizes for MD and BL crown diameter (maxilla=49, mandible= 63) for females from the three periods.

Table 7.18. Female MD and BL crown diameters (mm), by period

Tooth	Hissar I			Hissar II			Hissar III		
	N	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*
Mesiodistal diameters (mm)									
UI1	2	7.7	13.43	-	-	-	14	8.4	9.61
UI2	2	6.6	2.12	2	6.6	7.78	12	6.5	7.68
UC	2	7.2	6.36	4	7.1	2.87	23	7.4	6.21
UPM1	2	7.3	2.82	8	6.5	4.56	26	6.9	7.71
UPM2	2	7.2	2.82	8	6.2	3.55	31	6.8	5.39
UM1	2	10.4	4.24	7	10.0	6.45	31	10.0	6.05
UM2	2	10.9	11.31	8	9.4	7.8	36	9.8	7.29
UM3	2	8.9	12.02	7	8.3	4.1	28	9.3	7.57
LI1	5	4.9	3.36	2	5.8	4.24	16	5.1	5.52
LI2	5	5.4	10.54	2	6.1	3.54	23	5.8	3.47
LC	6	6.7	2.58	4	7.1	8.28	28	6.5	4.83
LPM1	6	6.6	6.02	7	6.9	7.21	33	6.7	5.63
LPM2	6	6.8	6.16	7	7.1	8.31	33	6.8	5.22
LM1	5	10.8	5.54	8	11.0	28.73	45	10.7	6.94
LM2	6	10.5	9.52	7	10.3	4.41	42	10.4	6.9
LM3	4	10.5	3.16	7	10.3	7.06	38	10.4	8.32
Buccolingual diameters (mm)									
UI1	2	7.6	4.95	2	6.9	7.78	15	7.4	5.74
UI2	2	7.0	5.65	2	6.3	9.89	13	6.5	3.29
UC	2	8.2	5.65	4	7.9	7.48	23	8.0	6.9
UPM1	2	9.9	6.36	8	9.0	4.52	25	8.9	8.18
UPM2	2	10.4	2.82	8	9.0	4.57	31	9.2	6.75
UM1	2	12.2	2.12	7	11.3	4.22	28	11.2	5.56
UM2	2	12.6	4.95	8	11.1	5.8	36	11.0	7.17
UM3	2	12.4	0.71	7	10.2	7.16	28	10.7	7.7
LI1	5	5.6	5	2	5.1	4.95	16	5.8	5.9
LI2	5	6.1	2.88	2	5.3	7.78	23	6.2	5.66
LC	6	7.4	5.15	4	6.8	4.57	28	7.3	5.18
LPM1	6	7.7	5.79	7	7.2	6.15	33	7.5	8.55
LPM2	6	8.0	5.16	7	7.9	11.51	33	8.0	6.95
LM1	5	10.4	6.46	8	10.4	4.44	45	10.4	5.81
LM2	6	10.2	7.69	7	9.6	5.25	42	10.0	5.82
LM3	4	9.5	8.73	7	9.5	5.25	38	9.7	5.69

U= upper (maxillary) teeth, L= lower (mandibular) teeth, I= incisor, C= canine, PM= premolar, M=molar

Figures 7.21 and 7.22 show the differences in MD and BL sizes in maxillary and mandibular teeth among the females. There was a variety of patterns for tooth size between females from the three periods, but no group had all teeth that were smaller or larger than those from the other groups. The MD dimension of the majority of the maxillary teeth was smaller for Hissar II than Hissar III and I, but the mandibular teeth for Hissar II had larger MD dimensions, except for M2 and M3 at Hissar I. Statistical analysis showed a significant difference in the size of four maxillary teeth (Table 7.18). The MD ($F=7.143$, $p=0.011$) and BL ($F=3.771$, $p=0.032$) dimensions of UPM2 showed a statistically significant difference. Individuals from Hissar I had a larger UPM2

(MD=7.2, BL=10.4mm) than those in Hissar II (MD=6.2, BL=9mm) and Hissar III (MD=6.8, BL=9.2mm). The MD (F=6.024, *p*=0.006) and BL (F=6.742, *p*=0.003) sizes of UM3 were statistically significantly different for all periods, and people in Hissar II had smaller UM3s (MD=8.3, BL=10.2mm) compared to Hissar I (MD=8.9, BL=12.4mm) and Hissar III (MD=9.3.5, BL=10.7mm). The BL sizes of UM1 (F=3.472, *p*=0.042) and UM2 (F=5.318, *p*=0.009) were statistically significantly different between all periods.

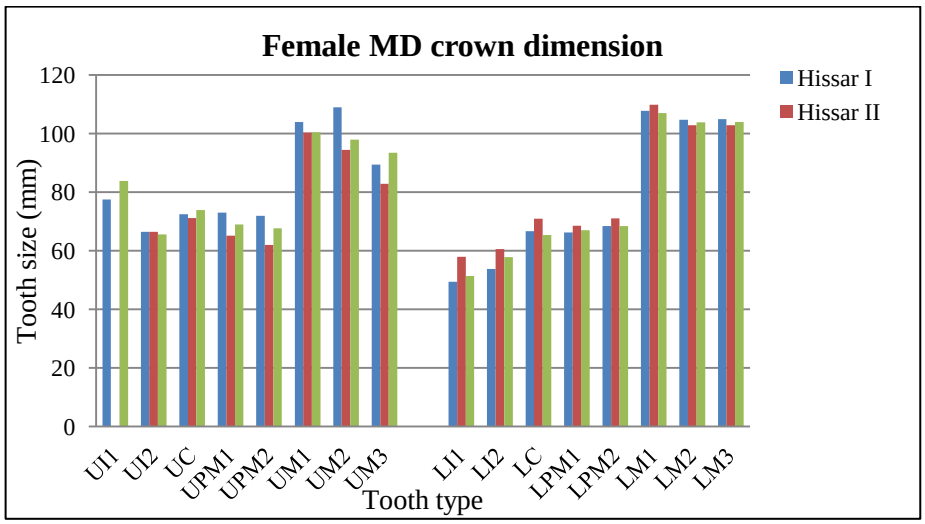


Fig 7.21. Female MD maxillary and mandibular crown size, by period

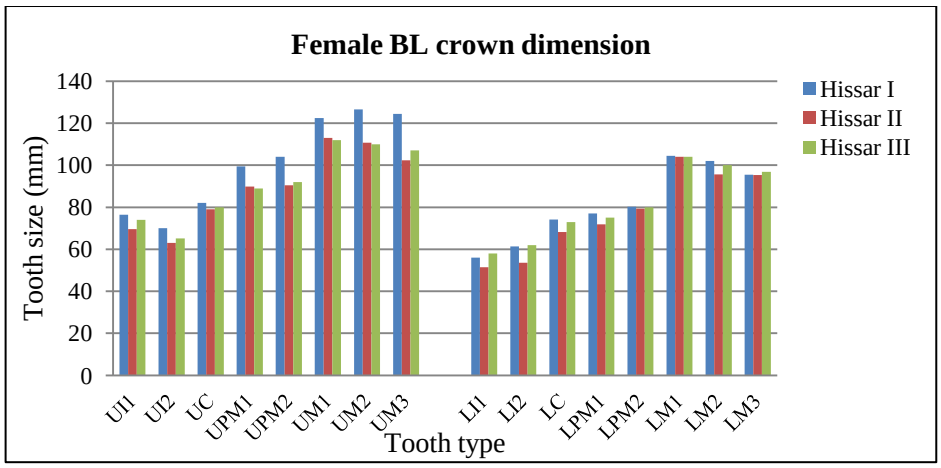


Fig 7.22. Female BL maxillary and mandibular crown size, by period

(ii) Multivariate Statistical Analysis of Dental Measurements

The results of two multivariate statistical procedures, Mahalanobis generalised distances (d^2), and principal component analysis (PCA), as well as the resulting cluster analyses and scatter plots included a comparison of craniofacial variation in individuals within periods by sex, a comparison of dental metrical variation in individuals between

periods by sex, and a comparison of dental metrical variations between males and females at *Tepe Hissar* by period.

(a) Comparisons of dental metrical variations of individuals within each period by sex

Mahalanobis generalised distances (d^2)

Mahalanobis generalised distances (d^2) were derived from 10 maxillary (n=75) and 10 mandibular (n=130) MD and BL crown dimensions (PM1, PM2, M1, M2, and M3). Applying Ward's method (Ward, 1963) and the Euclidean distances clustering algorithm to the Mahalanobis distances (d^2) resulted in dendrograms for each period for both maxillary and mandibular teeth by sex (Figures 7.23-28).

Hissar I

Mahalanobis distances for male and female dental metrical analysis from Hissar I are presented in Table 7.19 and 7.20, respectively. Table 7.19 shows that some males had greater similarities to each other. The smallest distances were between individuals A22, B5, B16, A23, and B2; B9 and B11; and A13 and B5 from this group. However, individual A13 showed the largest distance from the rest of the group.

Table 7.19. Dental metrical Mahalanobis distances (d2) for males from Hissar I

Mandible	A13	A22	A23	A7	B11	B16	B2	B5	B9
A13	0								
A22	17.598	0							
A23	19.288	1.69	0						
A7	9.889	7.709	9.399	0					
B11	12.07	5.528	7.218	2.181	0				
B16	19.172	1.574	0.116	9.283	7.102	0			
B2	20.852	3.253	1.564	10.962	8.781	1.68	0		
B5	17.625	0.027	1.663	7.736	5.555	1.547	3.226	0	
B9	13.338	4.260	5.95	3.449	1.268	5.834	7.514	4.287	0
Maxilla	A22	A23	A13	B5	B16				
A22	0								
A23	1.807	0							
A13	9.035	7.228	0						
B5	9.438	7.631	0.402	0					
B16	4.924	3.117	4.111	4.514	0				

Cluster analysis (Figure 7.23 a,b) shows that some of the males from Hissar I were similar to each other, while some showed larger distances. Hissar I males form two separate clusters (D1 and D2) in both Figures (a and b); in Figure 7.23a, cluster D1contains two sub groups, with individuals showing a greater similarity to each other but less similarity to neighbouring group D2.

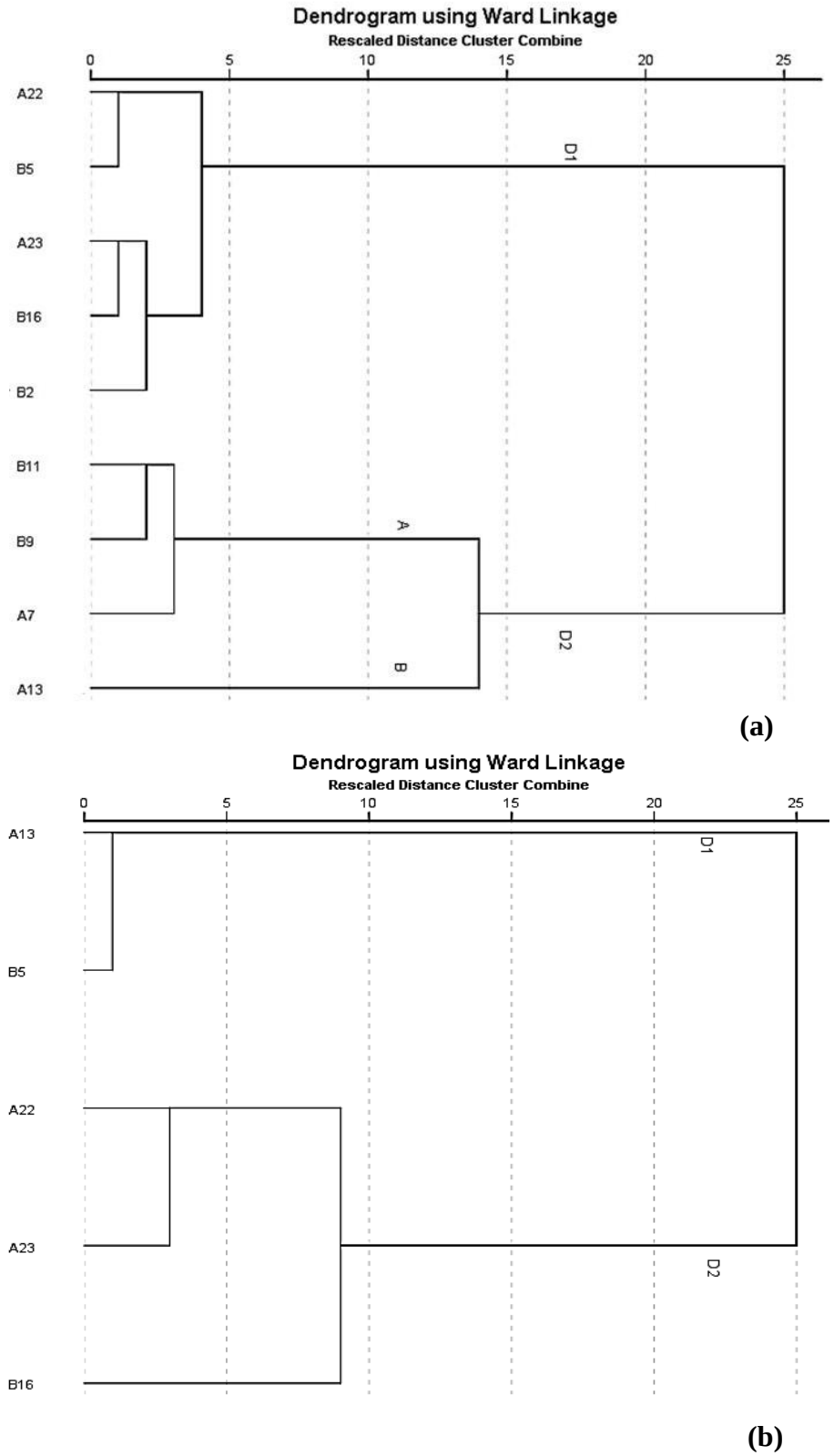


Fig 7.23. Dendrogram of biological relationships of males from Hissar I based on cluster analysis of Mahalanobis generalised distances (d2)- (a) mandible, (b) maxilla distances

Table 7.20 shows that the distances between female teeth were small in this group, and the smallest distances were between individuals A8 and A2, as well as between B3 and B10. These similarities are illustrated in Figure 7.24.

Table 7.20. Dental metrical Mahalanobis distances (d2) for females from Hissar I (mandibular)

Mandible	A17	A2	A26	A8	B10	B3
A17	0					
A2	2.321	0				
A26	1.577	0.744	0			
A8	2.330	0.010	0.754	0		
B10	4.254	1.933	2.677	1.924	0	
B3	4.776	2.455	3.199	2.445	0.521	0

Figure 7.24 shows that the females from Hissar I formed two separate clusters (D1 and D2). In cluster D1 individuals A2 and A8 were connected to each other but separated from individuals A26 and A17. Individuals in cluster D2 were more separated from cluster D1.

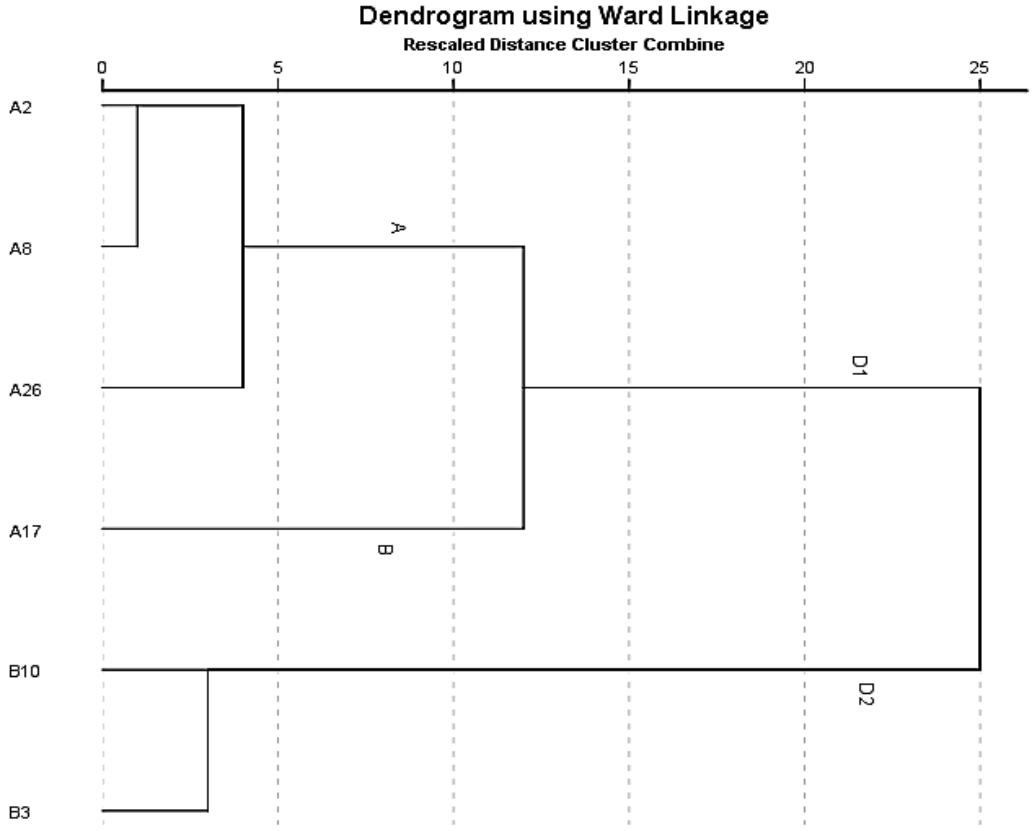


Fig 7.24. Dendrogram of biological relationships of females from Hissar I based on cluster analysis of Mahalanobis generalised distances (d2) (mandible)

Hissar II

Tables 7.21 and Table 7.22 show the Mahalanobis distances (d^2) for males and females in Hissar II for dental measurements, respectively. Table 7.21 shows that some males were not closely affiliated with each other. Individuals A132 and A218 were very distant from others in this group, but the smallest distances were between individuals B15, A48 and A32.

Table 7.21. Dental metrical Mahalanobis distances (d2) for males from Hissar II

Mandible	A132	A218	A49	B15	B23
A132	0				
A218	17.787	0			
A49	9.350	27.137	0		
B15	9.105	8.682	18.454	0	
B23	6.585	24.372	2.764	15.69	0
Maxilla	A200	A48	B23	B15	A32
A200	0				
A48	6.524	0			
B23	2.524	9.047	0		
B15	7.219	0.695	9.743	0	
A32	7.779	1.256	10.303	0.56	0

Cluster analysis (Figure 7.25a and b) shows that males formed two distinct clusters (D1 and D2). Figures 7.25a and b show cluster D1 to contain individuals affiliated with each other but separated from other individuals in cluster D2.

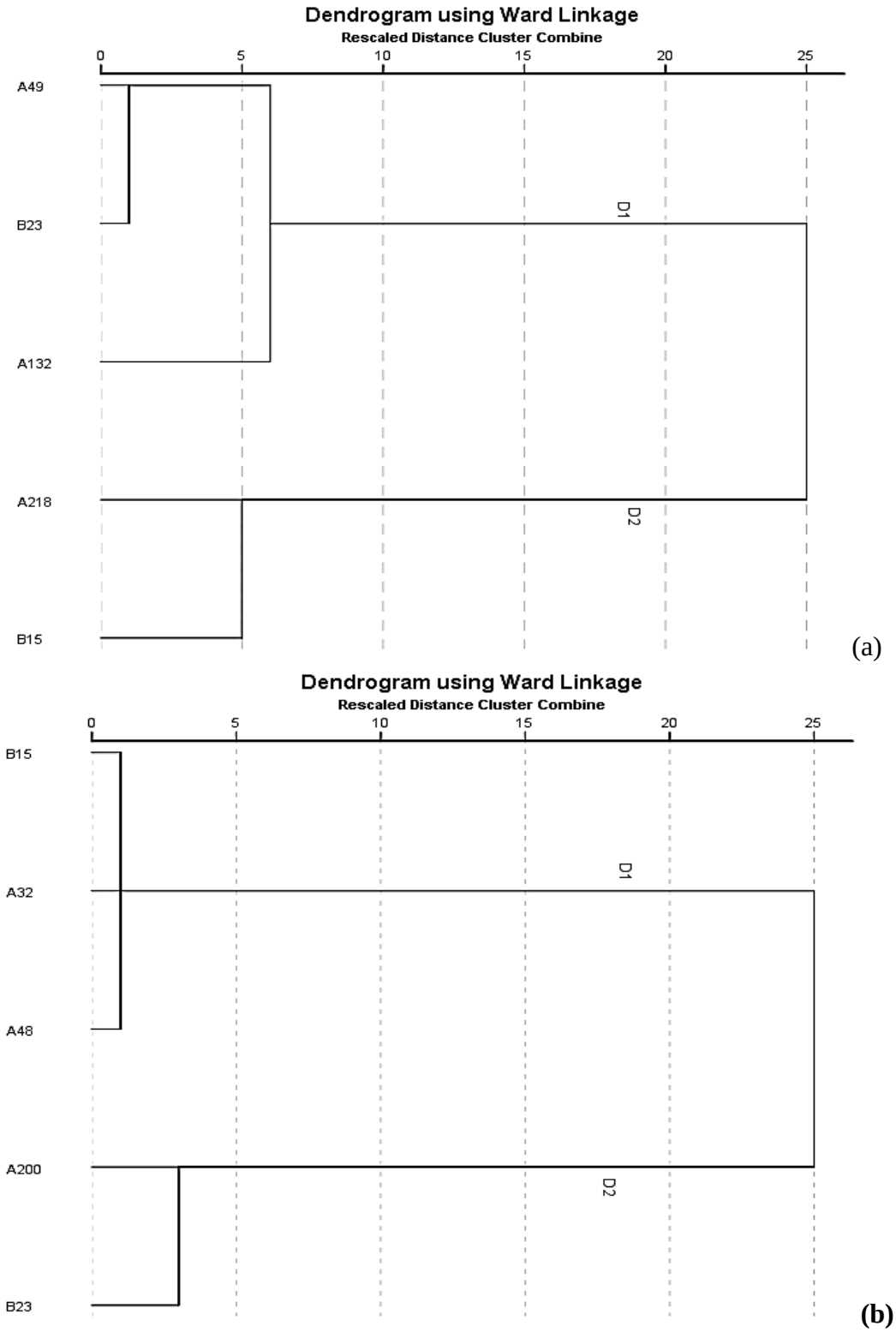


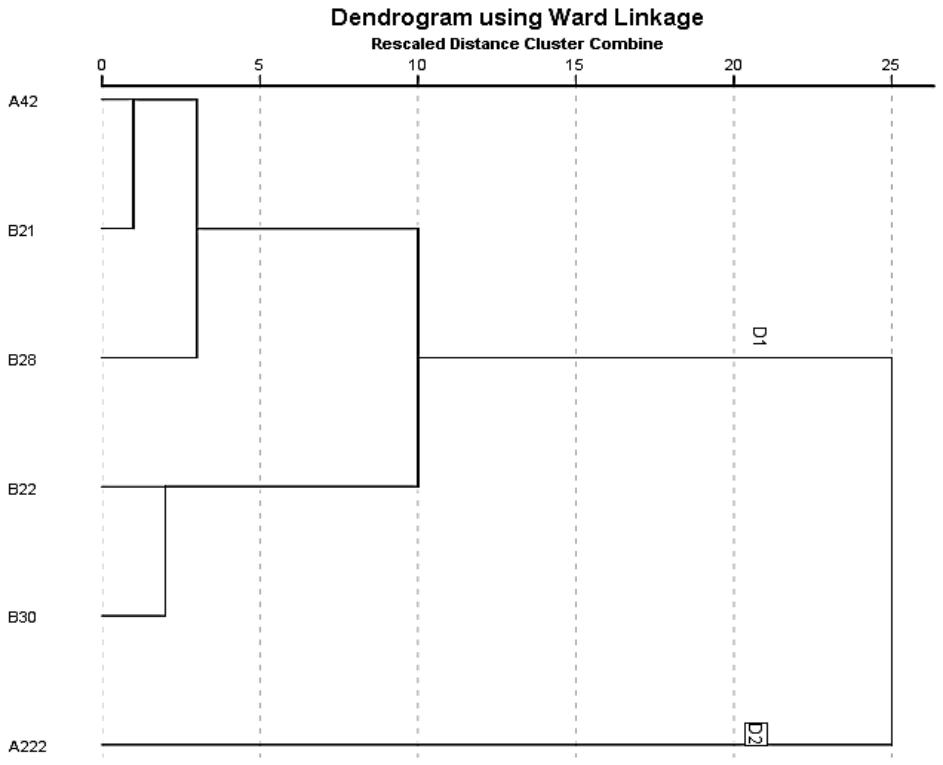
Fig 7.25. Dendrogram of biological relationships of males from Hissar II based on cluster analysis of Mahalanobis generalised distances (d2)- (a) mandible, (b) maxilla

Table 7.22 shows the smaller distances between females A128, A30, B22, B28, B26, and between B30, B21 and B24. Individuals B21 and A42 showed similarity to each other but individual A222 was distant from the others.

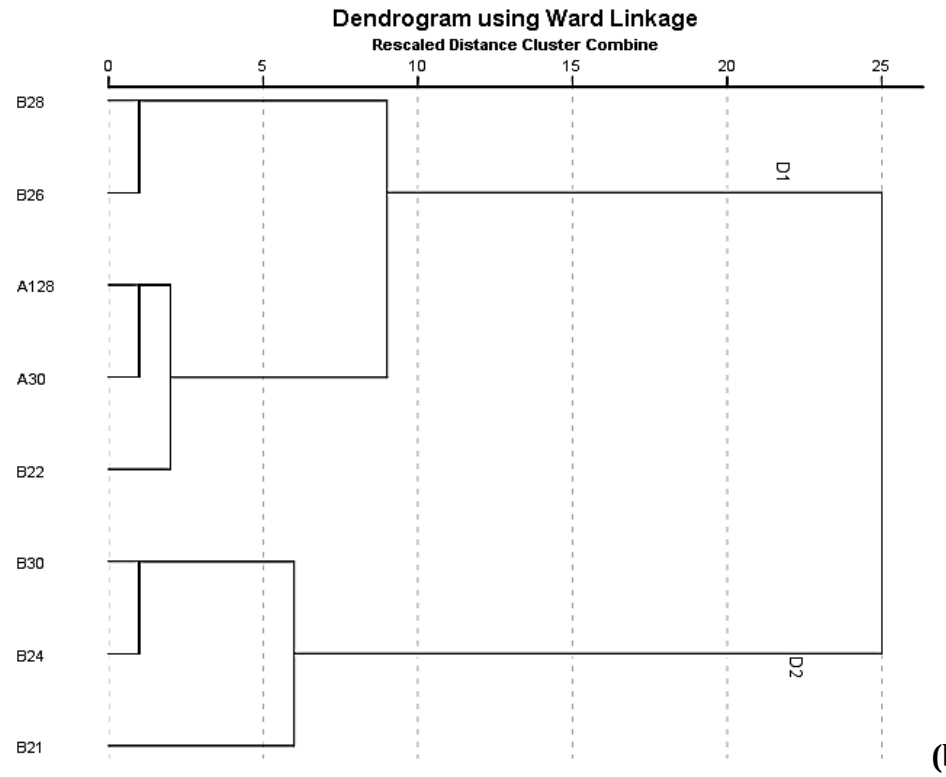
Table 7.22. Dental metrical Mahalanobis distances (d2) for females from Hissar II

Mandible	A222	A42	B21	B22	B28	B30		
A222	0							
A42	28.492	0						
B21	31.003	2.511	0					
B22	47.336	18.844	16.333	0				
B28	11.174	39.666	42.177	58.51				
B30	42.213	13.721	11.21	5.124	5.389	0		
Maxilla	A128	A30	B30	B21	B24	B22	B28	B26
A128	0							
A30	0.322	0						
B30	3.925	3.603	0					
B21	6.837	6.515	2.912	0				
B24	3.698	3.375	0.228	3.139	0			
B22	0.546	0.868	4.471	7.383	4.243	0		
B28	2.579	2.901	6.504	9.416	6.277	2.033	0	
B26	2.598	2.921	6.524	9.435	6.296	2.053	0.019	0

Figure 7.26 (a, b) shows two separate clusters (D1 and D2). Cluster D1 in both (a) and (b) contain the majority of individuals showing most similarity to each other. In dendrogram (a) individuals A42 and B21 were affiliated with each other but separated from individuals in the neighbouring cluster. Individual A222 was the most isolated. Cluster D1 (b) contains individuals with greater similarity to each other.



(a)

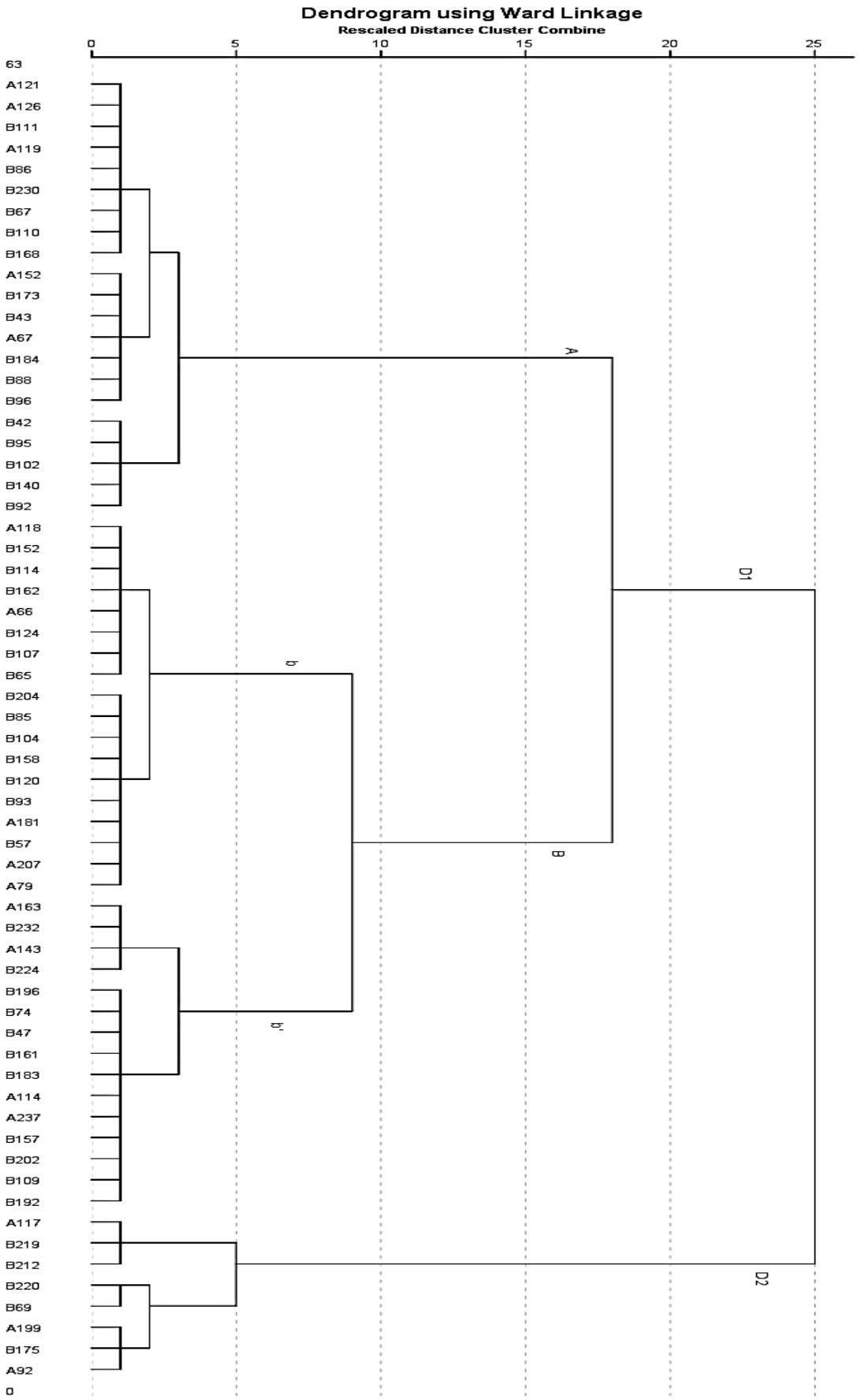


(b)

Fig 7.26. Dendrogram of biological relationships of females from Hissar II based on cluster analysis of Mahalanobis generalised distances (d2)- (a) mandible, (b) maxilla

Hissar III

Figure 7.27 (a,b) shows the Mahalanobis generalized distances (d^2) values for mandibular (n=62) and maxillary (n=26) crown dimensions, comparing males from Hissar III. In both plots the males form two major distinct clusters (D1 and D2), and D1 contains almost all the individuals which were then divided into two sub-clusters (A and B). There were three small groups within cluster A showing more similarity to each other than the other clusters. Cluster B divided into two smaller clusters (b, b'), each containing two smaller groups with within group similarity, but separated from the neighbouring groups. Cluster D2 was the most isolated. Nevertheless, the plots show that males were divided into several smaller groups with evidence of biological affinity within each group, but separated from those individuals from the neighbouring groups.


Dendrogram using Ward Linkage
Rescaled Distance Cluster Combine
0
5
10
15
20
25
63
A121
A126
B111
A119
B86
B230
B67
B110
B168
A152
B173
B43
A67
B184
B88
B96
B42
B95
B102
B140
B92
A118
B152
B114
B162
A66
B124
B107
B65
B204
B85
B104
B158
B120
B93
A181
B57
A207
A79
A163
B232
A143
B224
B196
B74
B47
B161
B183
A114
A237
B157
B202
B109
B192
A117
B219
B212
B220
B69
A199
B175
A92
0
A
B
b
b'
D1
D2

(a)

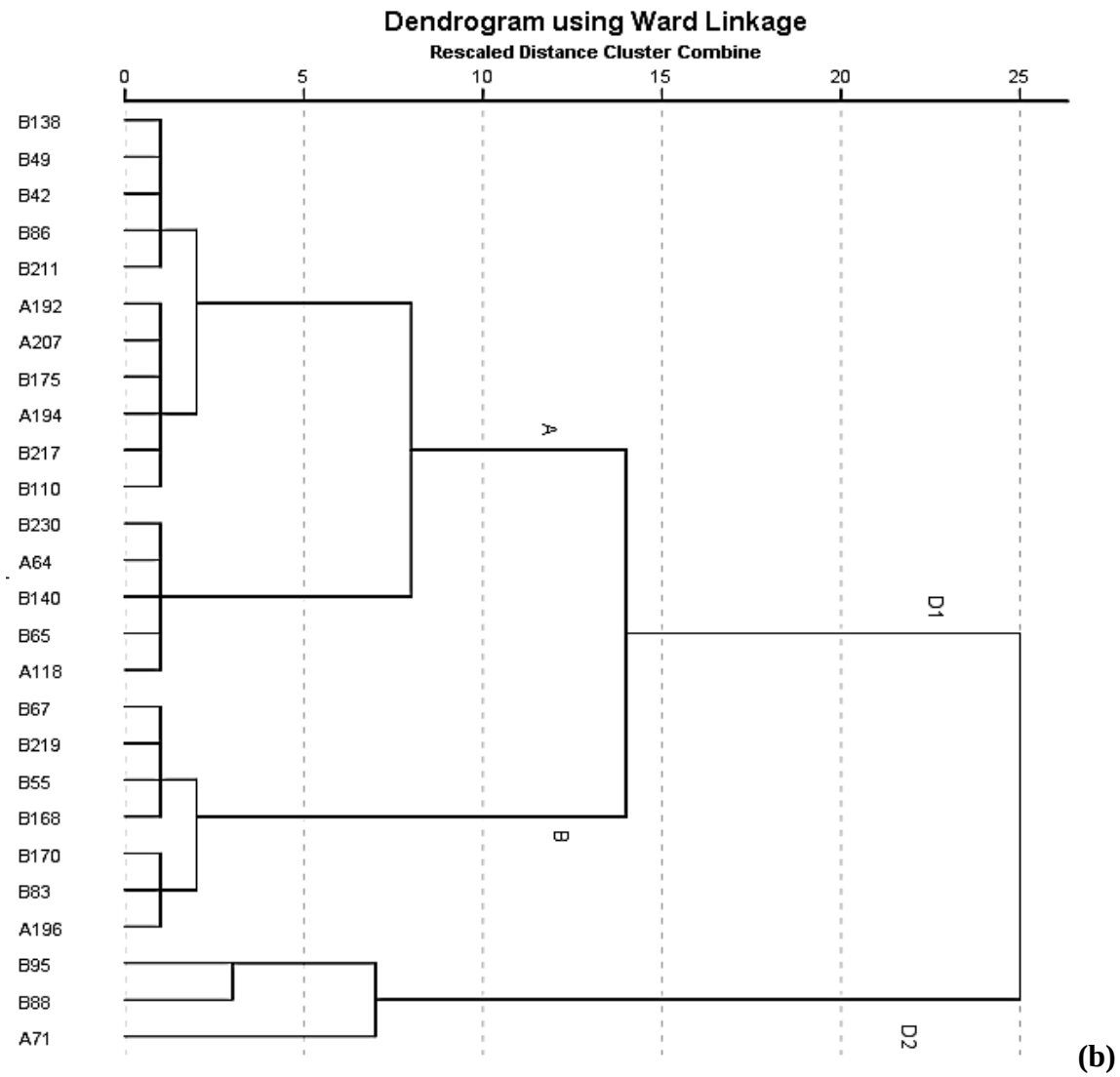
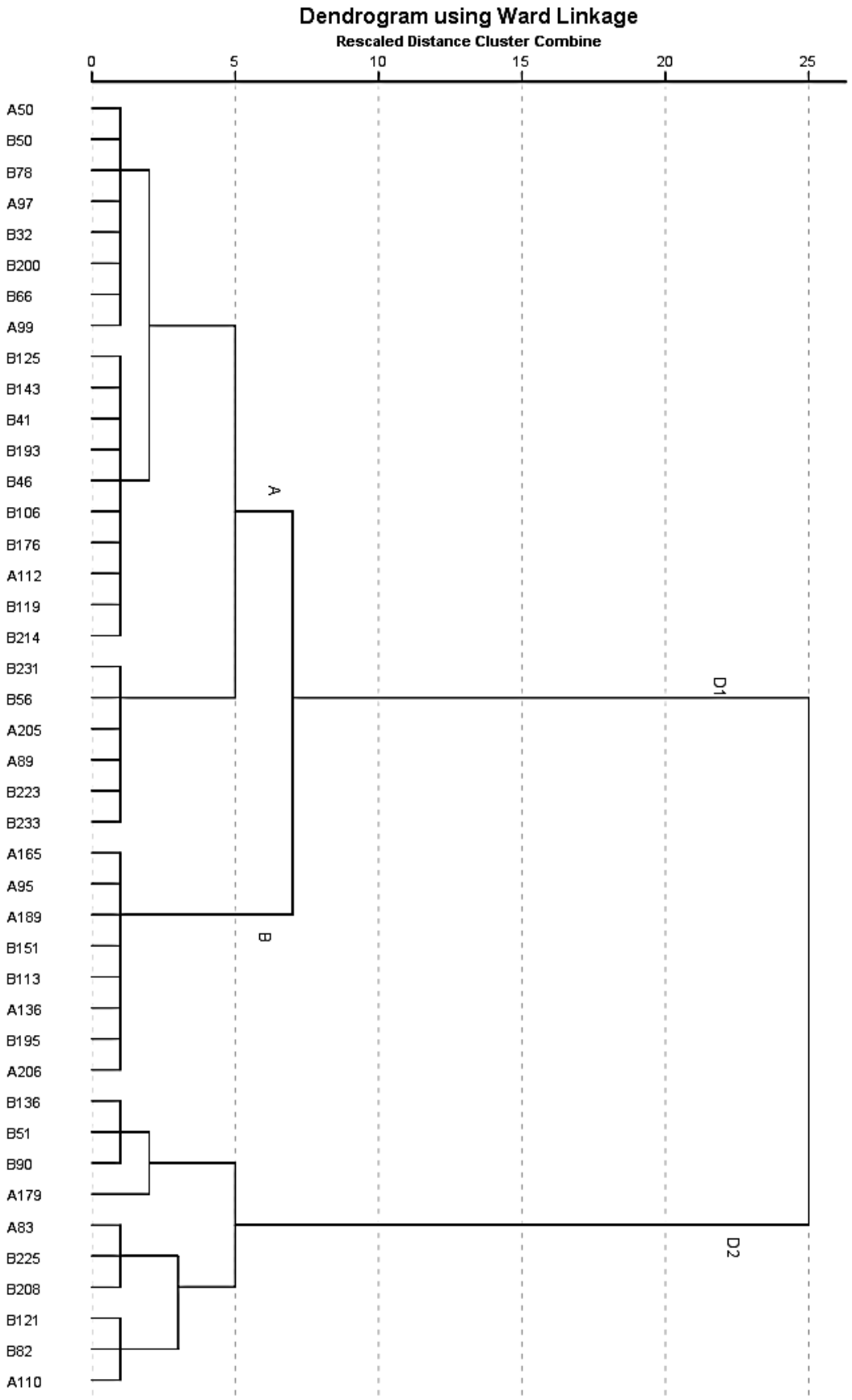
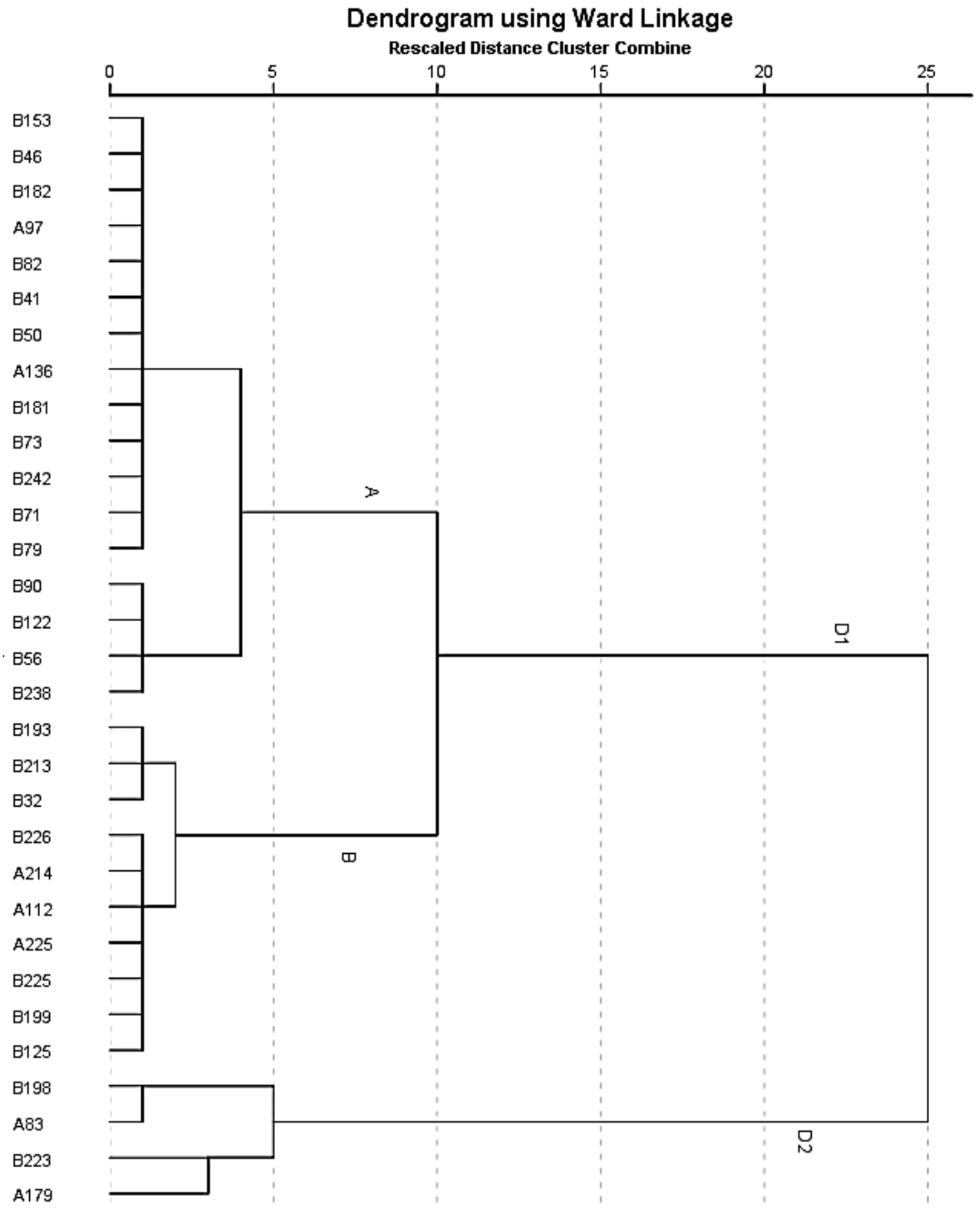


Fig 7.27. Dendrogram of biological relationships of males from Hissar III based on cluster analysis of Mahalanobis generalised distances (d2)- (a) mandible, (b) maxilla

Figure 7.28 (a and b) shows Mahalanobis generalized distances (d^2) values of mandibular (n=42) and maxillary (n=31) crown dimensions, comparing between female teeth. In both plots the females form two major distinct clusters (D1 and D2). Cluster D1 in both plots contains almost all the individuals and is divided into two sub-clusters (A and B), which contain small groups with within group similarities. Cluster D2 divides into smaller groups but was the most isolated cluster in both plots. The plots show that the females are also divided into smaller groups, with evidence of biological affinity within each group, but they were separated from individuals from the neighbouring groups in these clusters.


Dendrogram using Ward Linkage
Rescaled Distance Cluster Combine
0
5
10
15
20
25
A50
B50
B78
A97
B32
B200
B66
A99
B125
B143
B41
B193
B46
B106
B176
A112
B119
B214
B231
B56
A205
A89
B223
B233
A165
A95
A189
B151
B113
A136
B195
A206
B136
B51
B90
A179
A83
B225
B208
B121
B82
A110
A
B
D1
D2

(a)



(b)

Fig 7.28. Dendrogram of biological relationships of females from Hissar III based on cluster analysis of Mahalanobis generalised distances (d2)- (a) mandible, (b) maxilla

Principal component analyses (PCA)

PCA were performed separately for 10 maxillary (n=77) and 10 mandibular (n=134) MD and BL crown dimensions for individuals from the three periods. Table 7.23 shows the matrix obtained from the PCA of all the teeth. Two components were extracted from the within-individuals matrix for mandibular teeth that explain 61.2% of the total variance, and three were extracted from the within-individuals matrix for maxillary teeth, which explain 69.4% of the variance. In the PCA of the maxillary teeth, the most important variables that

were more responsible for producing group separation in the first component (PC1) were the BL dimensions of PM2, PM1, M3, and M1 (33.3% of variance), and in the second component (PC2) they were the MD dimensions of M3, PM1, PM2, and M1 (21.9% of variance). The variables for the third component (PC3) were M2MD and M2BL (14.2% of the variance). In the PCA of the mandibular teeth, the most important variables for producing group separation in the first component (PC1) were the BL dimensions of PM2, PM1, M2, M3, and M1 (44.76% of variance), and for the second component (PC2) it was the MD dimensions of M1, M3, and M2 (16.44% of variance). The scatter plots produced are presented in the following sections.

Table 7.23. Principal components loadings after varamix rotation for the 10 maxillary and 10 mandibular crown measurements from *Tepe Hissar*

	Maxilla			**Mandible**	
Variables	**PC1**	**PC2**	**PC3**	**PC1**	**PC2**
PM2BL	0.862	-0.064	0.151	0.827	0.064
PM1BL	0.843	0.009	-0.02	0.772	0.193
M2BL	0.236	-0.33	0.777	0.745	0.345
M3BL	0.823	0.091	-0.324	0.653	0.439
M1BL	0.792	0.198	0.06	0.589	0.436
M1MD	0.336	0.664	0.01	-0.064	0.948
M3MD	0.068	0.793	-0.158	0.402	0.617
M2MD	-0.194	0.111	0.853	0.451	0.516
PM1MD	0.03	0.751	-0.034	0.281	0.421
PM2MD	-0.093	0.676	0.006	0.221	0.374
Eigenvalues	182.3	119.8	77.78	196.5	72.2
Percent of Variance	33.3	21.9	14.2	44.76	16.44
Percent of Cumulative	33.3	55.2	69.4	44.76	61.2

Hissar I

Figure 7.29 (a, b) shows the biological distances between the individuals (female and male) from Hissar I on the first and second component scores based on mandibular and maxillary crown measurements, respectively. The plots show a clear separation between males and between females. There was a close similarity in the size of mandibular teeth between female A17 and male B9 among the other individuals in plot (a).

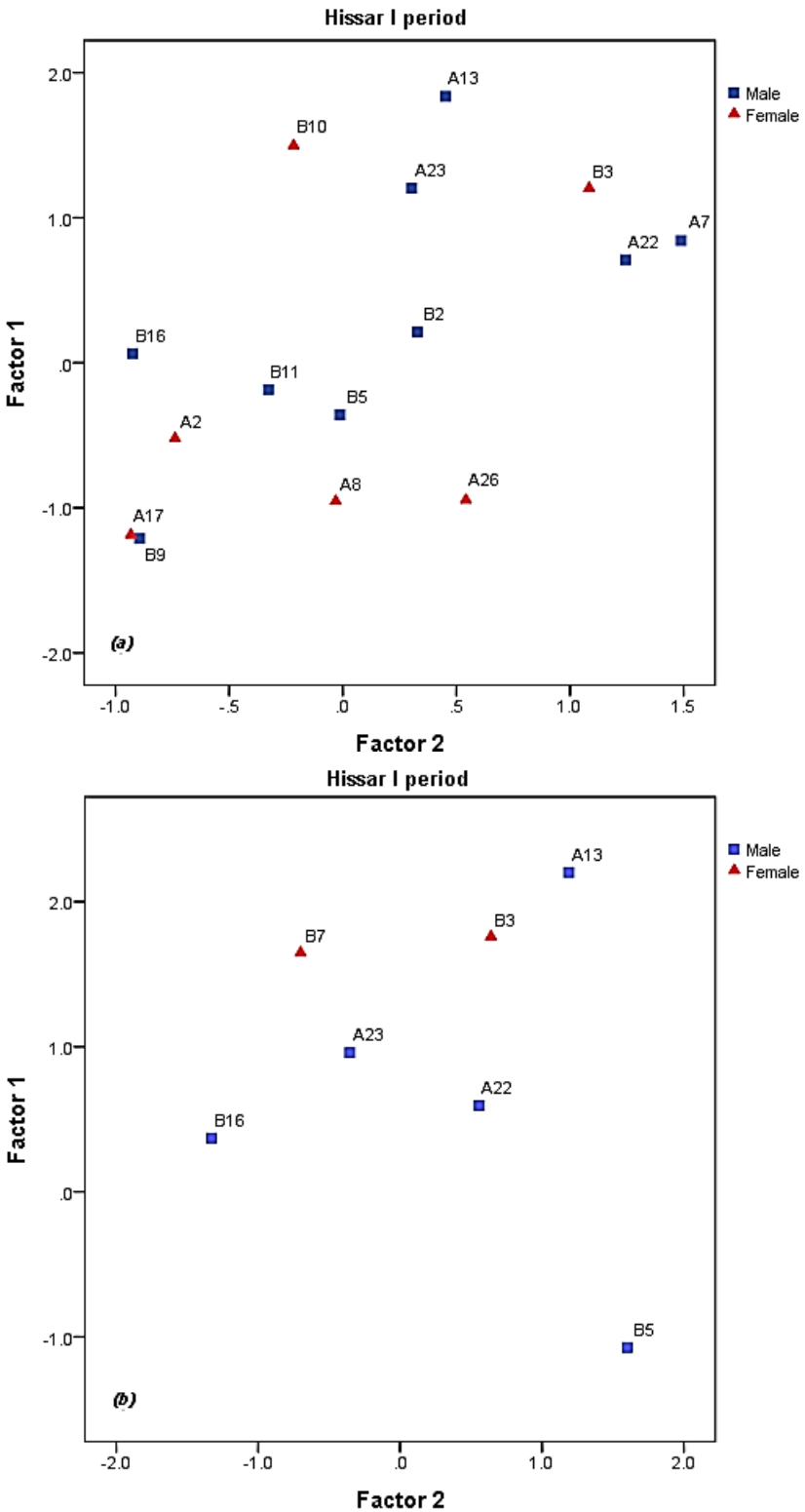


Fig 7.29. Scatter plot comparing distance among females and males from Hissar I based on factor scores generated from PCA for (a) 10 mandibular and (b) 10 maxillary dental measurements

Hissar II

Figure 7.30 (a and b) shows the biological distances between the male and female individuals from Hissar II on the first and second component scores, based on 10 mandibular and 10 maxillary crown measurements. The females and males were almost divided into two groups in both plots. However, in the first plot (a) males A132, A49, A32, and B23 were placed a small distance from each other, and females B22, B28, and B21. Females B24 and A222 isolated in this plot and separated from the rest of individuals. Males A218 and B15 were also isolated. In the second plot (b) the females showed closer affinity and female B28 was placed very close to male A200, while male B15 was isolated. This pattern matches the dendrograms for this period.

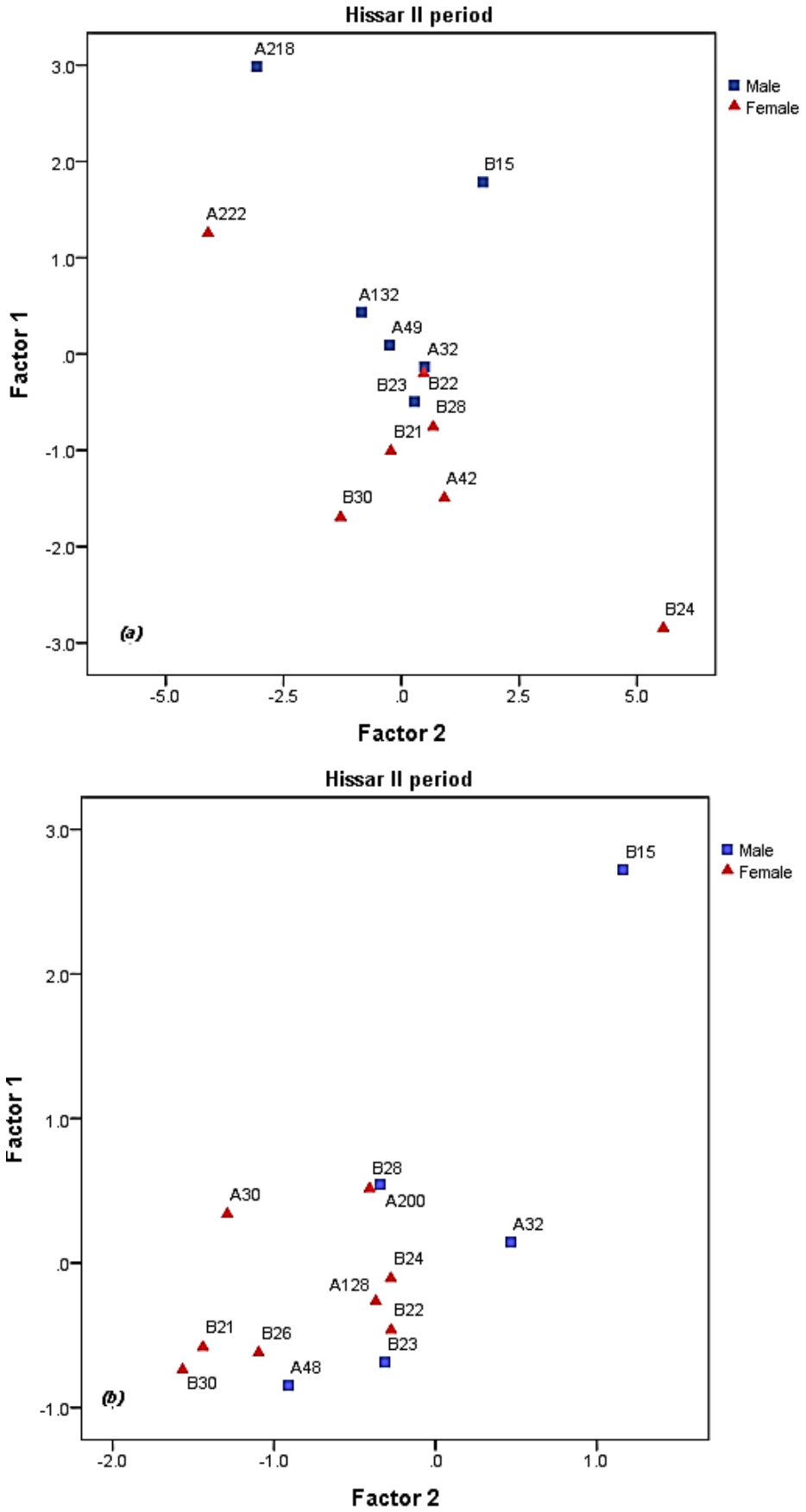


Fig 7.30. Scatter plot comparing distance among females and males from Hissar II based on factor scores generated from PCA for (a) 10 mandibular and (b) 10 maxillary dental measurements

Hissar III

Figure 7.31 (a, b) shows the distances between the male and female individuals from Hissar III based on the first and second component scores, based on mandibular and maxillary crown measurements. The majority of males and females showed a close connection to each other and to the opposite sex in both plots. However, there were some individuals from both sexes (e.g., male A117; females B121 and B223) who were located a larger distance from the rest of the group and did not show similarity to the others (a). Female A83 and male A71 were also isolated in the second plot (b). This pattern matches the dendrograms from this period.

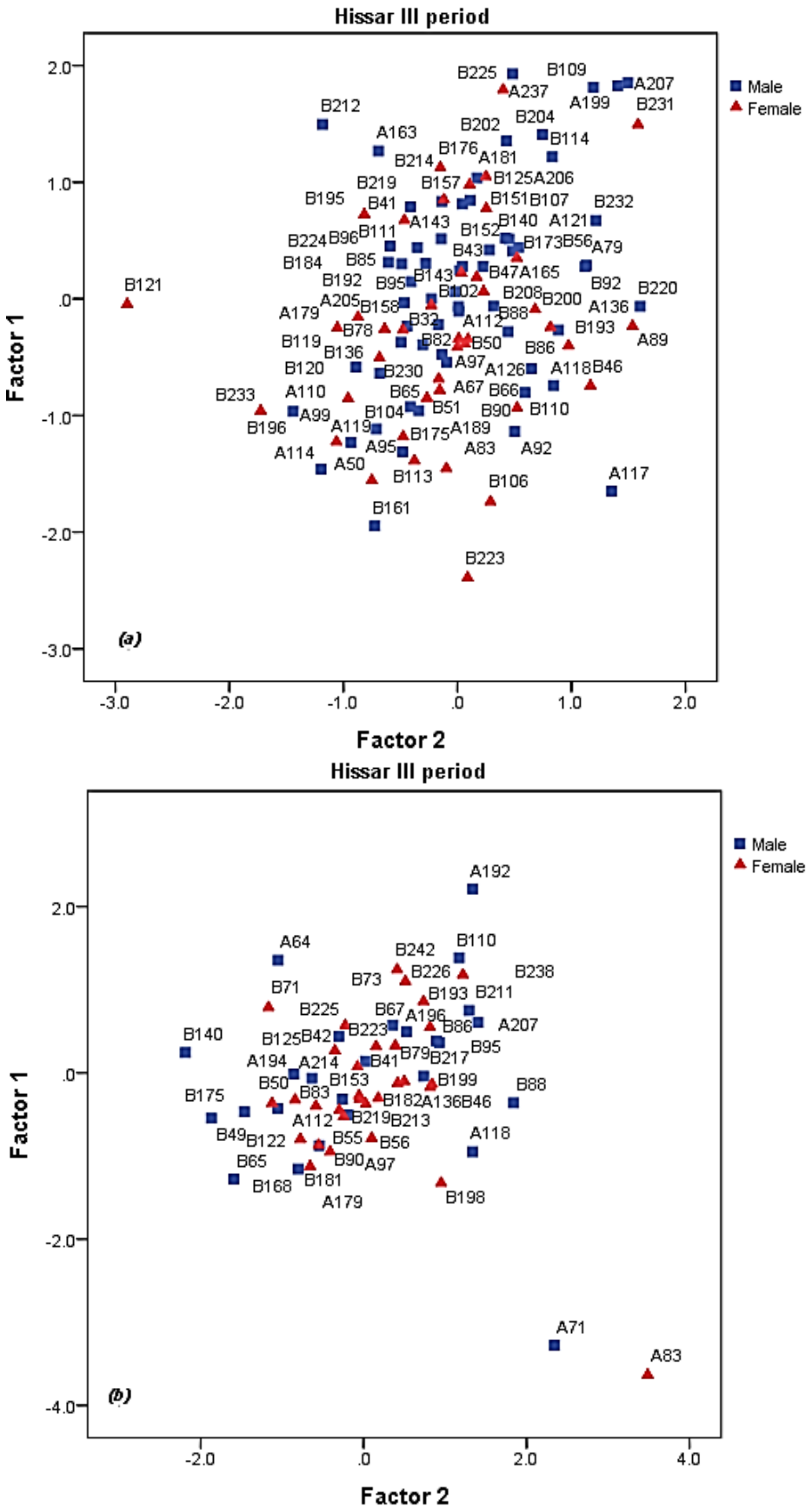


Fig 7.31. Scatter plot comparing distance among females and males from Hissar III based on factor scores generated from PCA to10 mandibular (a) and 10 maxillary (b) dental measurements

(b) Comparison of dental metrical variation in individuals between periods by sex

Figure 7.32 (a, b) shows the scatter plot of biological affinities between the males from the three periods at *Tepe Hissar*. The majority of the males from Hissar I were separated from each other, with some of them placed close to those in Hissar II, but the majority were placed a very small distance from individuals from Hissar III. The males from Hissar II were located in one area in both plots, but they were not very close together. However, they were closer to some males from Hissar III in both plots. Male A218 from Hissar II was isolated in the first plot (a). Some of the individuals from Hissar III showed smaller distances from each other, but some were a greater distance from the group (A117 (a) and A71 (b)).

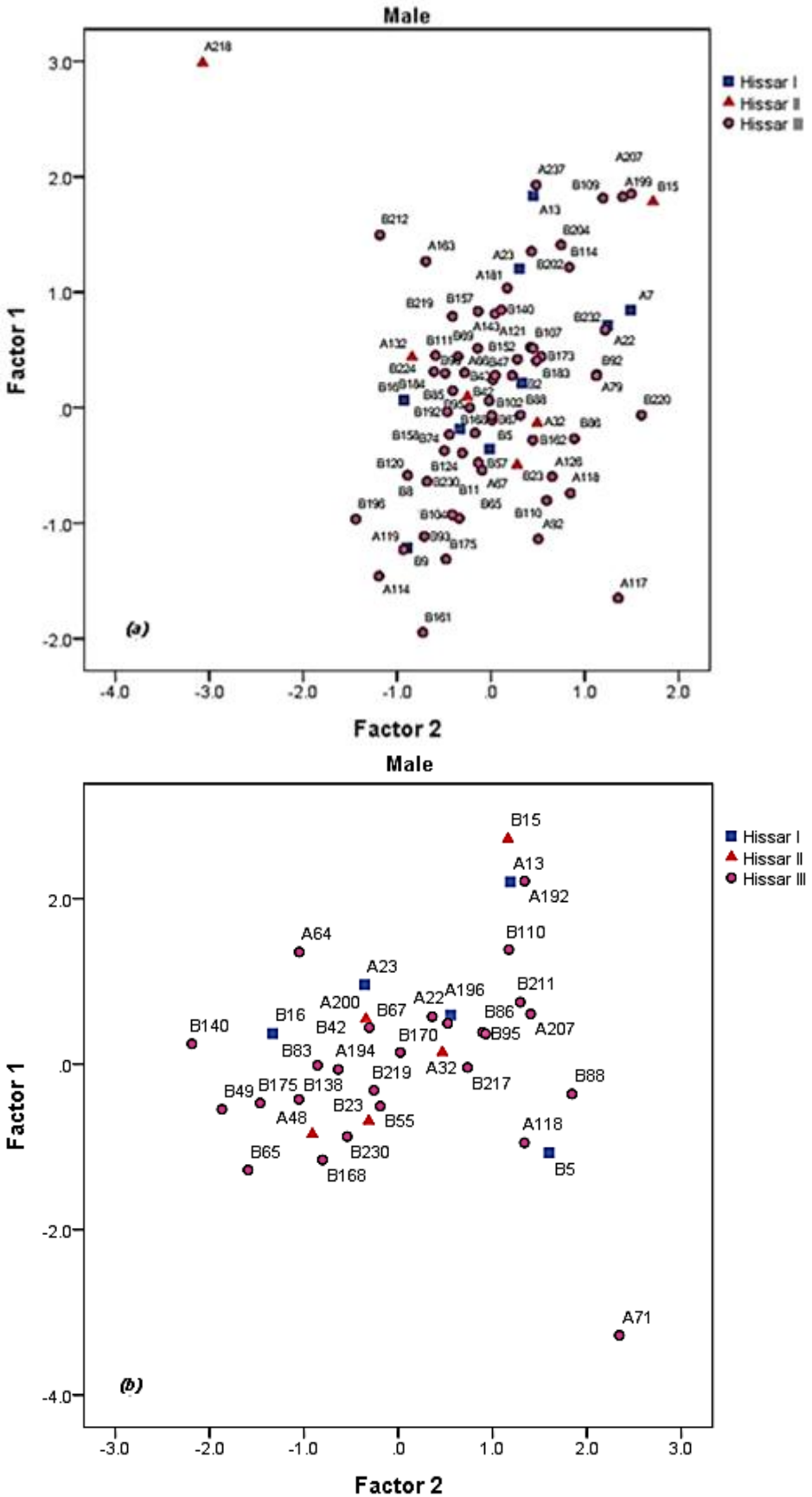


Fig 7.32. Scatter plot comparing distances among males from three periods at Tepe Hissar based on factor scores generated from PCA to 10 mandibular (a) and 10 maxillary (b) dental measurements

Figure 7.33 (a, b) shows affinities between the females from the three periods at *Tepe Hissar*. The Hissar I females were a large distance from each other in both plots, but two were close to individuals from Hissar III and one to Hissar II. However in both plots individuals B3, B7 and B10 from Hissar I were a larger distance away from the rest of group. The individuals from Hissar II, in both plots, were located in one area of the plot, with varying distances from each other. Some showed similarity to Hissar III, but some were located a larger distance and from the rest of the group. For example, individuals A222 and B24 were isolated in the first plot. The females from Hissar III were not all similar to each other and some (e.g., B223, A83) showed greater dissimilarity and were a larger distance from the others in both plots.

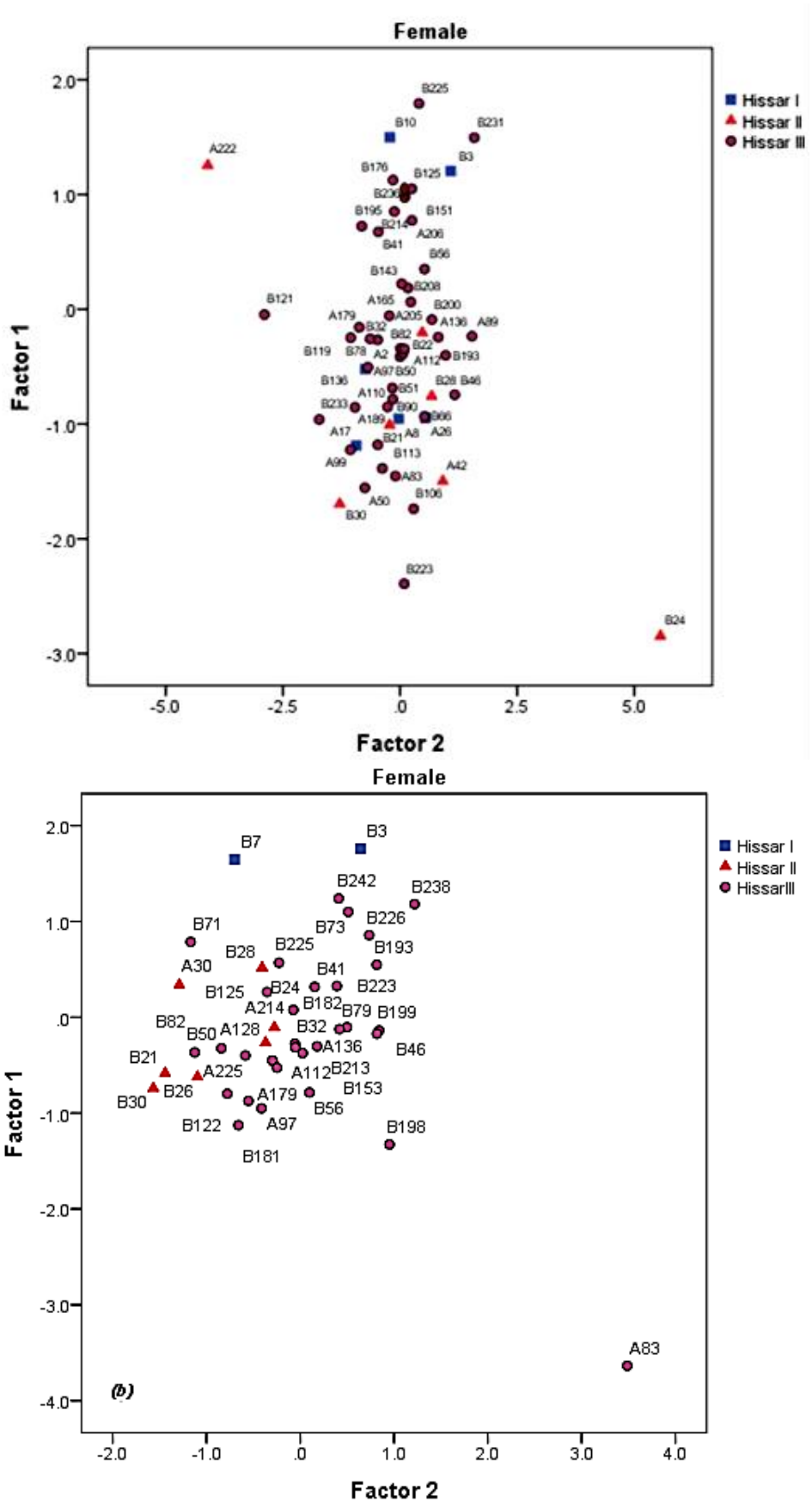


Fig 7.33. Scatter plot comparing distance among females from three periods at Tepe Hissar based on factor scores generated from PCA to 10 mandibular (a) and 10 maxillary (b) dental measurements

(c) Comparison of dental metrical variation between males and females at *Tepe Hissar* by period

Four components were extracted from the within-individuals matrix which had Eigenvalues greater than 1.0. Together these four components explain 98.9% of the total variance. The varimax rotated PCA Eigenvalues for each factor are presented in Table 7.24. The most important and responsible variables in producing group separation in the first component (PC1) were maxillary PM1, PM2 and M2 BL and MD diameters, and M1 and M3 BL diameters (63.1% of variance), and in the second component (PC2) it was the mandibular PM2, M1 and M3 BL and MD diameters, and the PM1MD diameter (17.2% of variance).

Table 7.24. Principal component loadings after varamix rotation

Variables	***PC1***	***PC2***	***PC3***	***PC4***
UM2BL	.972	.084	-.172	.075
UPM2BL	.929	-.027	.352	.079
UM1BL	.916	.166	.345	-.089
UM2MD	.891	-.155	-.353	.237
UPM1BL	.858	.027	.508	-.056
UM3BL	.853	-.110	.474	.189
UPM2MD	.723	-.073	.137	.673
UPM1MD	.669	-.209	.541	.464
LPM2MD	-.043	.931	-.328	-.143
LPM1MD	-.198	.880	.004	-.342
LM3BL	-.131	.872	-.171	.420
LPM2BL	-.018	.857	.441	.256
LM3MD	.199	.854	.399	.249
LM1MD	-.173	-.772	.383	-.386
LM1BL	-.093	.738	.453	.308
UM1MD	.485	.021	.860	-.075
LM2MD	.141	.032	.849	.413
UM3MD	.008	.291	.098	.940
LM2BL	.278	.490	.500	.637
LPM1BL	.335	.575	.460	.577
Eigenvalues	188.1	51.4	34.4	21.1
Percent of Variance	63.1	17.2	11.5	7.1
Percent of Cumulative	63.1	80.3	91.8	98.9

Figure 7.34 shows a scatter plot generated from these two components and displays the females from Hissar II and III were located close to each other, but well away from Hissar I females who were isolated in this plot. The males from Hissar I and Hissar III were located a small distance from each other and from females from Hissar II and III. However, the males from Hissar II were located a large distance from the Hissar I and III males.

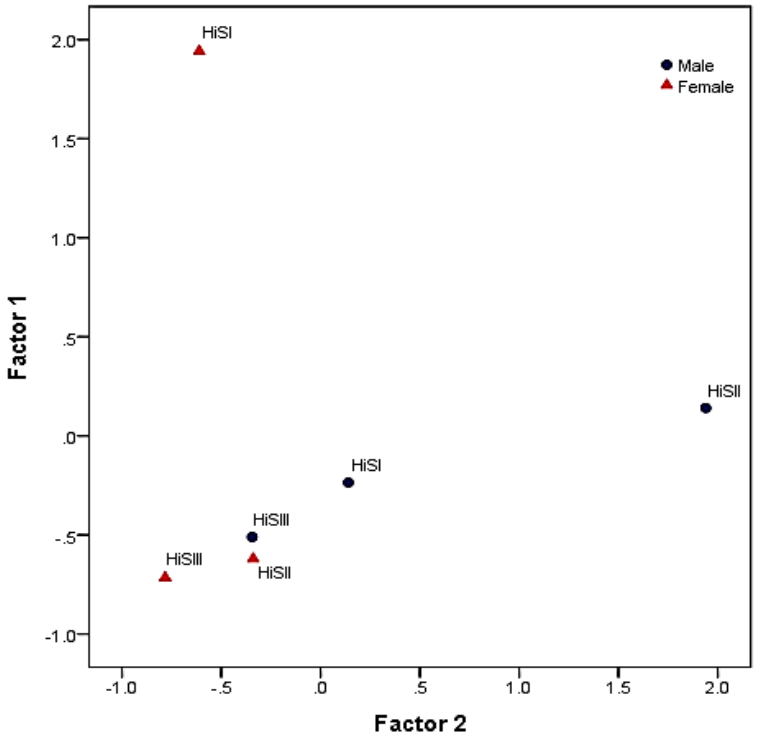


Fig 7.34. Scatter plot comparing distance among females and males from three periods at Tepe Hissar based on the factor scores generated from PCA to 10 mandibular and 10 maxillary dental measurements

7.3.3. Stature

(i) Hissar I

Table 7.25 illustrates the summary results for mean stature for females and males for the Hissar I sample. A total of 12 individuals had long bones for stature estimation, of which seven were male and five were female. The mean stature of females in Hissar I was almost identical to males, with males being 0.5cm taller (167.3cm) than females (166.8cm-t=0.850, p=0.934). The minimum height of males and females for this period was almost identical, with an average of 155cm for both sexes. The maximum height for females was 186cm while it was 180cm for males. The next tallest female and male were 169cm and 174cm, respectively.

Table 7.25. Hissar I: Male and female mean stature (cm)

	No.	*Mean*	*Min.*	*Max.*	*S.D.*
Male	7	167.3	155	180	8.077
Female	5	166.8	155	186	11.84

(ii) Hissar II

A total of 30 individuals from this period had preserved long bones available for stature estimation; 11 were male and 19 were female. Females (Table.7.26) were on average 12cm shorter (158.5cm) than males (171cm) (t=4.362, p=0.001). The shortest

female was 147cm while this was 159cm for males. The next shortest female and male were 150cm and 164cm, respectively. The maximum height for females of this period was 172cm, while it was 13cm more for males (185cm).

Table 7.26. Hissar II: Male and female mean stature (cm)

	No.	***Mean***	***Min.***	***Max.***	***S.D.***
Male	11	171	159	185	7.183
Female	19	158.5	147	172	7.303

(iii) Hissar III

Table.7.27 shows mean stature for the 176 Hissar III adults. Male were 12.4cm taller (171.7cm) than females (159.3cm) (t= 12.836, p=0.001). The minimum height for the females was 138cm and almost 155cm for males. The maximum stature for males and females was almost identical at 189cm and 187cm, respectively.

Table 7.27. Hissar III: Male and female mean stature (cm)

	No.	***Mean***	***Min.***	***Max.***	***S.D.***
Male	86	171.7	155	189	6.01
Female	90	159.3	138	187	6.74

(iv) Comparison of Male Mean Stature Distribution at *Tepe Hissar* by Period

Table 7.28 and Figure 7.35 illustrate the distribution of heights for males by ten centimetre stages. Comparison of the stature ranges for males from all periods shows that a higher percentage of males were between 161-170cm height. The percentage of tall males between 171-180cm in height was higher in the Hissar III period (44.2%), than in Hissar II (36.4%) and Hissar I (28.6%). There was one male (9%) from Hissar II and six (7%) from Hissar III with mean statures greater than 180cm when compared to zero for Hissar I (insignificant (K-S=0.521, p=0.916)).

Table 7.28. Comparison of male stature, by period

Stature range	**Hissar I**		**Hissar II**		**Hissar III**	
	No.	*%*	*No.*	*%*	*No.*	*%*
140<	0	0%	0	0%	0	0%
140-150	0	0%	0	0%	0	0%
151-160	1	14.3%	1	9.1%	2	2.3%
161-170	4	57.1%	5	45.4%	40	46.5%
171-180	2	28.6%	4	36.4%	38	44.2%
>180	0	0%	1	9.1%	6	7%
Total	7	6.7%	11	10.5%	86	82%

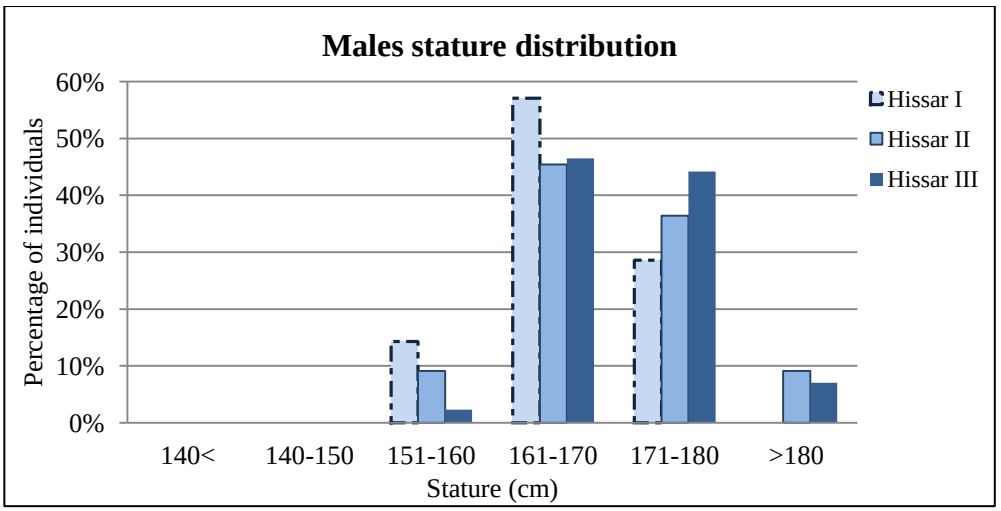


Fig 7.35. Male stature distribution by period

(vi) Comparison of Female Mean Stature Distribution at *Tepe Hissar* by Period

Table 7.29 and Figure 7.36 illustrate the distribution of height for females at *Tepe Hissar* by ten centimetre stages. There were no females shorter than 150cm in the Hissar I period (0%), compared to 3 (16%) and 4 (4%) in the Hissar II and Hissar III periods, respectively. There was one female shorter than 140cm (1%) from Hissar III. The percentage of females between 151 and 160cm was higher in Hissar III (52%) than Hissar II (37%) and Hissar I (20%). In contrast, the proportion of females with stature between 161 and 170cm was higher in Hissar I (60%) than in Hissar II (42%) and Hissar III (39%). There was one female from Hissar II (5%) and two from Hissar III (2%) with average statures between 171 and 180cm (significant (*K-S=0*.246, *p*=0.01)).

Table 7.29. Comparison of female stature, by period

Stature range	**Hissar I**		**Hissar II**		**Hissar III**	
	NO.	***%***	***NO.***	***%***	***NO.***	***%***
140<	0	0%	0	0%	1	1%
140-150	0	0%	3	16%	4	4%
151-160	1	20%	7	37%	47	52%
161-170	3	60%	8	42%	35	39%
171-180	0	0%	1	5%	2	2%
>180	1	20%	0	0%	1	1%
Total	5	4%	19	16%	90	78%

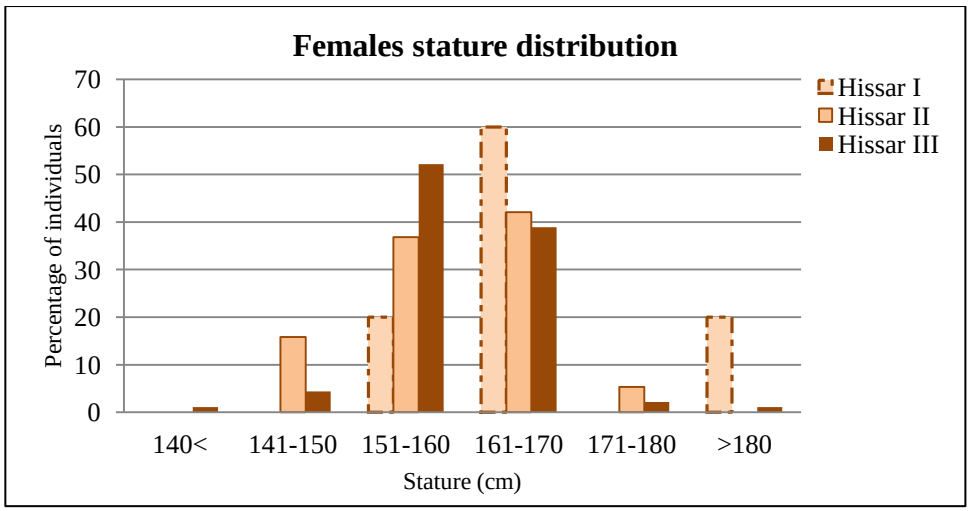


Fig 7.36. Female stature distribution, by period

(vi) Comparison of Adult Mean Stature at *Tepe Hissar*

Comparison of stature for males and females for all periods are presented in Table 7.30 and Figure 7.37. In Hissar I, males were shorter in stature (by 3.7cm and 4.4cm, respectively) than in Hissar II (171cm) and Hissar III (171.7cm) (insignificant (t=1.861, *p*=0.98). However, Hissar II mean statures were almost identical to Hissar III males who were, on average, 0.7cm taller than Hissar II males. Among females, Hissar I females were the tallest. They were on average 7.8cm taller than Hissar II females and 7.5cm taller than females from Hissar III (insignificant (*t*=0.704, *p*=0.084)).

However, the number of females from Hissar I preserved well enough for measurements to be taken were fewer than at Hissar II and III.

Table 7.30. Comparison of mean statures at Tepe Hissar population by sex and period (cm)

Period	Male			Female		
	NO.	*Mean*	*Range*	*NO.*	*Mean*	*Range*
Hissar I	7	167.3	155-180	5	166.8	155-186
Hissar II	11	171	159-185	19	158.5	147-172
Hissar III	86	171.7	155-189	90	159.3	138-187

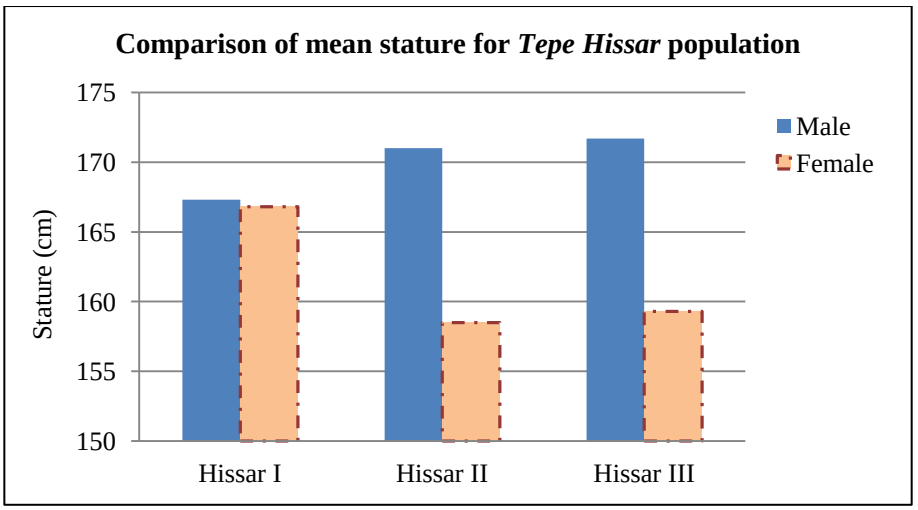


Fig 7.37. Comparison of mean statures for the Tepe Hissar population by sex and period

7.4. Non-Metric Traits Variation: Normal Variation

The data for cranial, skeletal and dental non-metric trait frequency and variability for the *Tepe Hissar* population are presented as: a comparison within the periods of non-metric trait variation for each trait by sex, a comparison between the periods of non-metric trait variation for each trait by sex for males and females independently, and finally a comparison of each traits with the sexes pooled between the periods.

7.4.1. Cranial Non-Metric Trait Frequency

A total of 150 individuals were examined for 48 cranial non-metric traits; six were from Hissar I, 17 were from Hissar II, and 127 were from Hissar III. Table 7.31 tabulates the frequency distribution of the traits by sex and period. This table also provides statistically significant differences when comparing the females and males for each trait by period independently.

Table 7.31. Cranial non-metric trait frequency for Tepe Hissar, by sex and period

		Hissar I			Hissar II			Hissar III		
Code	**Variables**	***Male (n=5)***	***Female (n=1)***		***Male (n=6)***	***Female (n=11)***		***Male (n=74)***	***Female (n=53)***	
		A/O (%)	*A/O (%)*	***P***	*A/O (%)*	*A/O (%)*	***P***	*A/O (%)*	*A/O (%)*	***P***
1	*Highest nuchal-line present*	4/5(80)	0/1(0)		3/6 (50)	7/11(63.6)		44/74(59.5)	29/53 (54.7)	
2	*Ossicle at lambda*	1/5(20)	0/1(0)		1/6(16.7)	0/11(0)		12/73(16.4)	3/53(5.7)	
3	*Lambdoid ossicle present*	3/5(60)	0/1(0)		3/6(50)	3/11(27.3)		36/74(48.6)	29/53(54.7)	
4	*Parietal foramen present*	2/5(40)	1/1(100)		4/6(66.7)	9/11(81.8)		56/74(75.7)	33/53(62.3)	
5	*Bregmatic bone present*	0/5(0)	0/1(0)		0/6(0)	0/11(0)		0/74 (0)	1/53(1.9)	
6	*Metopism*	0/5(0)	0/1(0)		0/6(0)	1/11(9.1)		2/74(2.7)	1/53(1.9)	
7	*Coronal ossicle present*	0/5(0)	0/1(0)		0/6(0)	0/11(0)		8.74(10.8)	7/53(13.2)	
8	*Epipteric bones present*	1/5(20)	0/1(0)		0/5(0)	1/11(9.1)		12/74(16.2)	14/53(26.4)	
9	*Fronto-temporal articulation*	2/4(50)	1/1(100)		3/6(50)	8/11(72.7)		66/74(89.2)	44/53(83)	
10	*Parietal notch bone present*	0/4(0)	1/1(100)		3/6(50)	5/11(45.5)		36/73(49.3)	21/52(40.4)	
11	*Ossicle at asterion*	1/4(25)	0/1(0)		3/6(50)	2/11(18.2)		22/71(31)	11/52(21.2)	
12	*Auditory tori present*	0/5(0)	0/1(0)		0/6(0)	1/11(9.1)		0/73(0)	2/52(3.8)	
13	*Foramen of Huschke present*	1/4(25)	0/1(0)		0/6(0)	0/11(0)		8/72(11)	13/52(25)	‡
14	*Mastoid foramen exsutural*	1/4(25)	0/1(0)		5/6(83.3)	5/11(45.5)		58/72(73.6)	33/52(63.5)	
15	*Mastoid foramen sutural*	2/4(50)	1/1(100)		4/6(66.7)	6/11(54.5)		39/72(54.2)	28/52(53.8)	
16	*Posterior condylar canal*	1/2(50)	0/1(0)		4/6(66.7)	5/8(62.5)		41/66(62.1)	30/47(63.8)	
17	*Condylar facet double*	0/2(0)	0/1(0)		2/6(33.3)	2/8(25)		6/60(10)	5/44(11.4)	
18	*Precondylar tubercle*	0/2(0)	0/1(0)		2/6(33.3)	3/8(37.5)		21/61(34.4)	15/45(33.3)	
19	*Anterior condylar canal double*	0/2(0)	0/1(0)		3/6(50)	1/8(12.5)		19/65(29.2)	8/46(17.4)	
20	*Foramen ovale incomplete*	0/2(0)	0/1(0)		0/6(0)	1/10(10)		5/66(7.6)	0/50(0)	‡
21	*Foramen spinosum open*	0/2(0)	0/1(0)		1/6(16.7)	1/11(9.1)		13/68(19.1)	6/50(12)	
22	*Accessory lesser palatine foramen*	2/3(66.7)	0/1(0)		5/6(83.3)	10/11(90.9)		60/70(85.7)	39/48(81.2)	
23	*Palatine torus*	1/3(33.3)	1/1(100)		3/6(50)	5/11(45.5)		34/69(49.3)	26/47(55.3)	
24	*Maxillary torus*	1/4(25)	0/1(0)		3/6(50)	3/11(27.3)		13/72(18.1)	9/47(19.1)	
25	*Zygomatico-facial foramen*	3/4(75)	1/1(100)		5/6(83.3)	9/11(81.8)		61/73(83.6)	38/48(79.2)	
26	*Supra-orbital foramen complete*	0/4(0)	1/1(100)		3/6(50)	6/11(54.5)		22/73(30.1)	12/52(23.1)	
27	*Frontal notch or foramen*	3/5(60)	1/1(100)		5/6(83.3)	6/11(54.5)		47/73(64.4)	34/53(65.4)	
28	*Anterior ethmoid foramen exsutural*	1/4(25)	1/1(100)		4/5(80)	10/10(100)		50/71(70.4)	36/48(75)	
29	*Posterior ethmoid foramen*	1/4(25)	0/1(0)		4/6(66.7)	8/9(88.9)		50/71(70.4)	35/48(72.9)	
30	*Accessory infraorbital foramen*	0/4(0)	0/1(0)		0/6(0)	0/10(0)		10/72(13.9)	4/49(8.2)	
31	*Suprameatal spine*	2/5(40)	1/1(100)		5/6(83.3)	5/11(45.5)		46/74(62.2)	30/53(56.6)	

32	*Occipital foramen*	2/5(40)	0/1(0)	3/6(50)	2/11(18.2)	15/74(20.3)	11/53(20.8)	
33	*Frontal grooves*	1/5(20)	1/1(100)	3/6(50)	5/11(45.5)	17/74(23)	22/53(41.5)	‡
34	*Foramen vesalious*	0/5(0)	0/1(0)	1/6(16.7)	5/11(45.5)	23/74(31.1)	19/53(35.8)	
35	*Nasal foramina*	1/5(20)	0/1(0)	4/6(66.7)	7/11(63.6)	42/74(56.8)	27/53(50.9)	
36	*Inferior squamous foramen*	0/5(0)	0/1(0)	0/6(0)	1/11(9.1)	6/74(8.1)	6/53(11.3)	
37	*Inferior parietal foramen*	0/5(0)	0/1(0)	1/6(16.7)	0/11(0)	5/74(6.8)	4/53(7.5)	
38	*Occipitomastoid ossicle*	0/5(0)	0/1(0)	1/6(16.7)	0/11(0)	3/74(4.1)	4/53(7.5)	
39	*Marginal tubercle*	1/5(20)	0/1(0)	1/6(16.7)	4/11(36.4)	30/74(40.5)	12/53(22.6)	‡
40	*Zygomaxillary tubercle*	1/5(20)	0/1(0)	0/6(0)	1/11(9.1)	19/74(25.7)	11/53(20.8)	
41	*Trochlear spur*	0/5(0)	0/1(0)	0/6(0)	2/11(18.2)	1/74(1.4)	8/53(15.1)	‡
42	*Sutura mendosa*	1/5(20)	0/1(0)	1/6(16.7)	1/11(9.1)	11/74(14.9)	0/53(0)	‡
43	*Mental foramen*	0/5(0)	0/1(0)	0/6(0)	1/11(9.1)	6/74(8.1)	1/53(1.9)	
44	*Sagittal ossicle*	0/5(0)	0/1(0)	0/6(0)	2/11(18.2)	5/74(6.8)	1/53(1.9)	
45	*Supratrochlear notch*	0/5(0)	0/1(0)	0/6(0)	0/11(0)	4/74(5.4)	0/53(0)	
46	*Palatine bridging*	0/5(0)	0/1(0)	0/6(0)	1/11(9.1)	6/74(8.1)	5/53(9.4)	
47	*Peterygoalar bridge*	0/5(0)	0/1(0)	1/6(16.7)	1/11(9.1)	2/74(2.7)	0/53(0)	
48	*Squamomastoid suture*	0/5(0)	0/1(0)	0/6(0)	0/11(0)	6/74(8.1)	3/53(5.7)	

‡ Statistically significant differences at $p \leq 0.05$ value. A/O: affected/observed

(i) Comparison of Non-Metric Cranial Trait Frequency by Period for each Trait, by Sex

(a) Hissar I

A total of 48 cranial traits were scored in six individuals; 25 (52%) and 11(23%) traits were present in male skulls and in one female skull from Hissar I, respectively. The sample size from Hissar I was very small and the frequency of cranial traits should be viewed with caution. The highest nuchal-line (80%), zygomatico-facial foramen (75%), lambdoid ossicle (60%), and frontal foramen (60%) appeared more frequently in males (Figure7.38). The parietal notch bone and supra-orbital foramen complete occurred in the female skull but none of the males had these traits; in the later periods these traits are seen among males and females in both Hissar II and Hissar III (insignificant). However, the very small female sample size (n=1) should be considered.

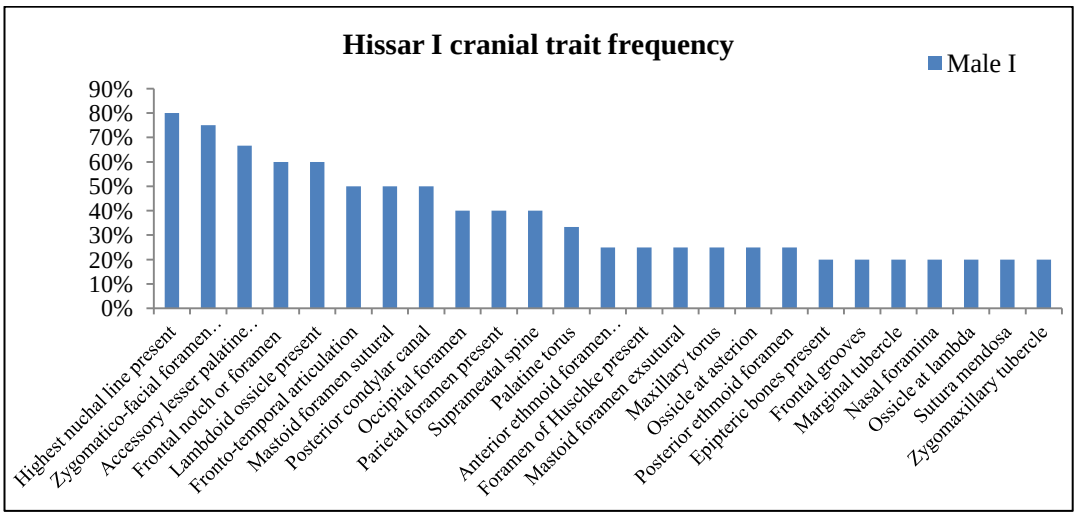


Fig 7.38. Hissar I: Cranial non-metric trait frequency (males)

(b) Hissar II

A total of 48 cranial traits were recorded, and 33 (69%) and 40 (83%) traits were present among males and females, respectively. The frequencies of traits were generally different for both sexes (Figure7.39); women showed more variation in traits than men (insignificant). The males had the highest frequency of mastoid foramen exsutural (67%), frontal notch (83%), and suprameatal spine (83%), but the lowest frequency (16.7%) for foramen vesalious, marginal tubercle, sutura mendosa, foramen spinosum open, ossicle at lambda, occipitomastoid ossicle, and inferior parietal foramen. The last three traits were completely absent in females. The females showed the highest frequency for parietal foramen (82%), fronto-temporal articulation (73%), and highest nuchal-line (64%). Traits such as foramen vesalious, marginal tubercle, epipteric bone,

zygomaxillary tubercle, auditory tori, palatine bridging, metopism, inferior squamous foramen, mental foramen, sagittal ossicle, trochlear spur, and foramen ovale incomplete occurred more frequently in females compared to the males but the differences were not statistically significant. The last 10 traits were present among females, but were totally absent in males (Table7.31).

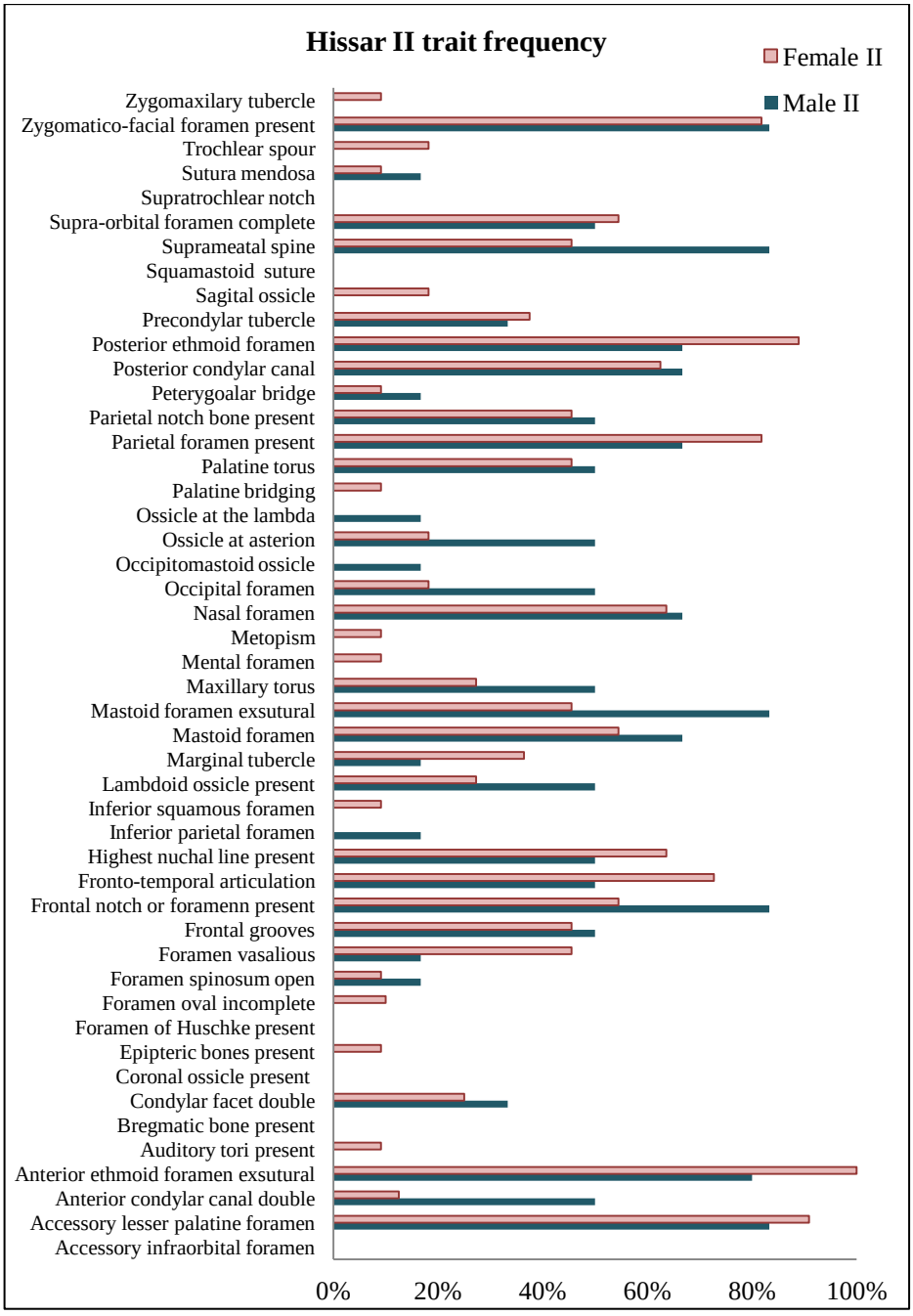


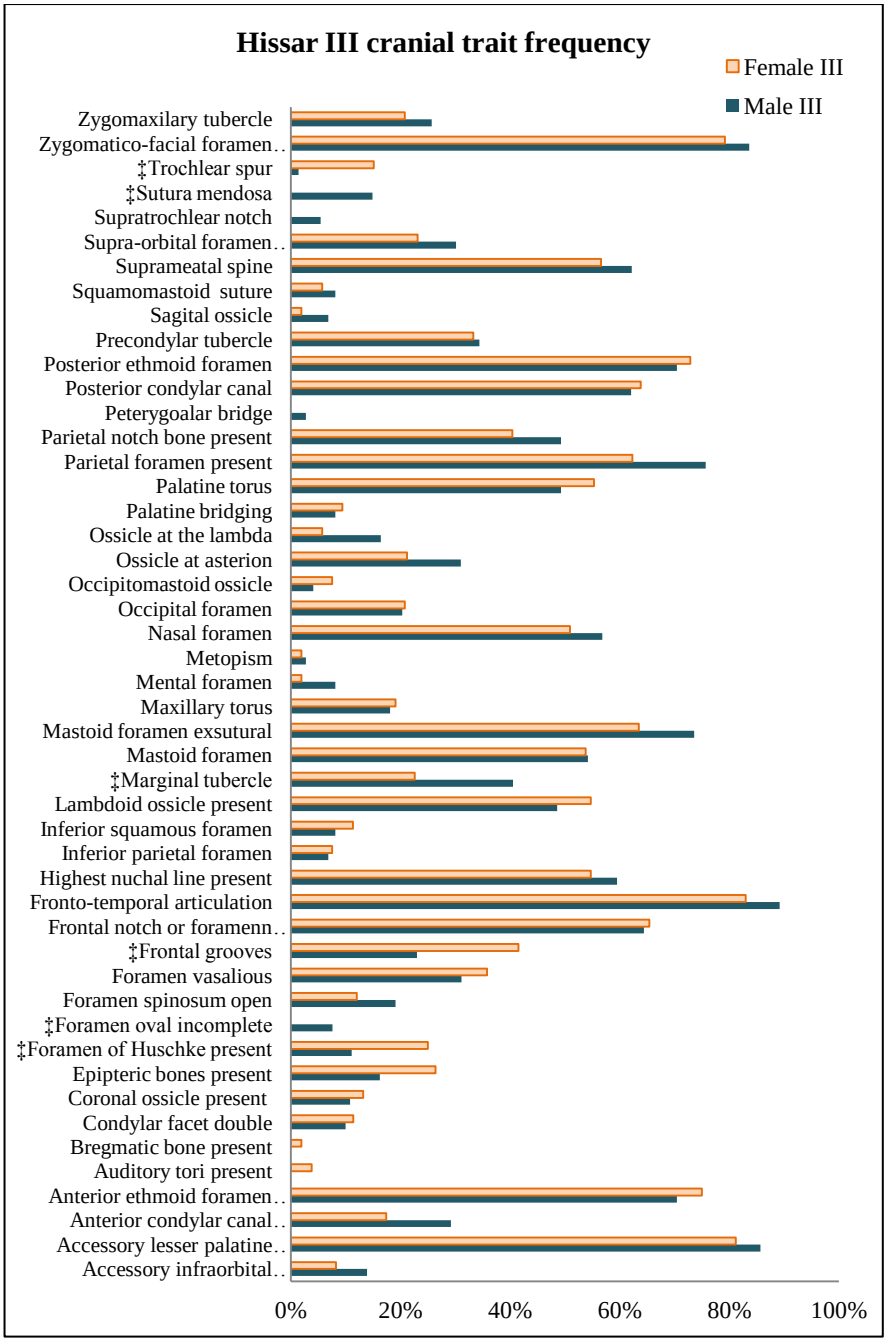
Fig 7.39. Hissar II: Cranial non-metric trait frequency by sex

(c) Hissar III

The number and variety of cranial traits observed in Hissar III were greater than previous periods. Of the 48 cranial traits recorded, 47 (98%) and 45 (94%) were present

among males and females, respectively. However, the prevalence rates generally differed between the sexes. The males showed a higher frequency for fronto-temporal articulation (89%), parietal foramen (76%), and mastoid foramen exsutural (74%), and a lower frequency for trochlear spur (1%) (Table7.31). Some traits such as sutura mendosa (15%), foramen oval incomplete (8%), supratrochlear notch (5%), and peterygoalar bridge (3%) were recorded among males but were absent in females (Figure 7.40).

The occurrence of the frontal notch (83%) and accessory infraorbital foramen (81%) was higher in females than in males and the bregmatic bone and auditory tori were only present in females. The Hissar III period showed the highest sexual dimorphism (12% (6/49)) compared to Hissar II (0%) and Hissar I (0%). There were statistically significant differences in the frequency of foramen of Huschke (p=0.042), frontal grooves (p=0.026), marginal tubercle (p=0.034), foramen ovale incomplete (p=0.042), trochlear spur (p=0.003), and sutura mendosa (p=0.003) between the sexes.



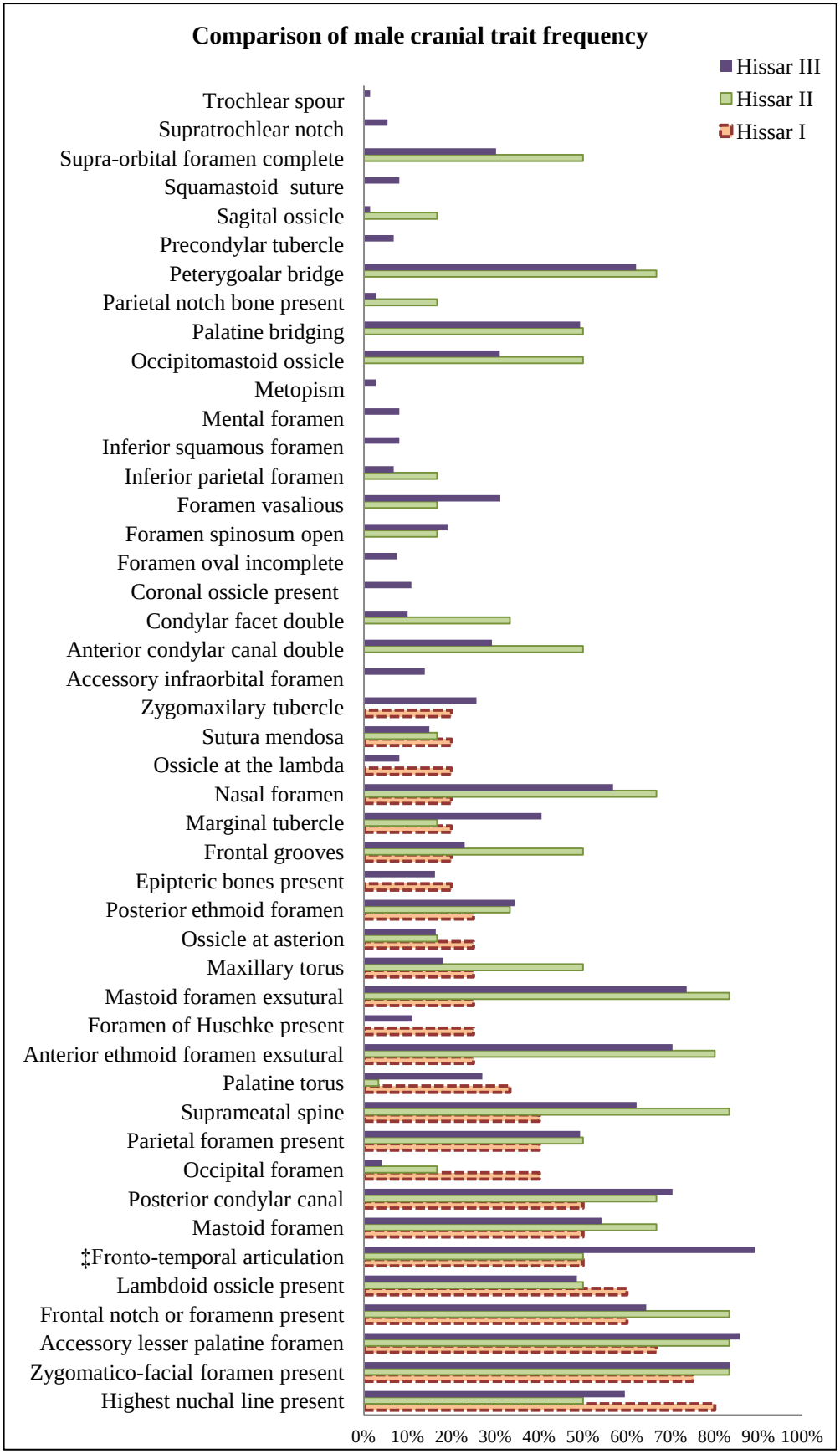
‡ Statistically significant differences: p≤0.05

Fig 7.40. Hissar III: Cranial non-metric trait frequency

(ii) Comparison of Non-Metric Cranial Trait Frequency between Periods for each Trait Independently by Sex

Figures 7.41 and 7.42 compare cranial trait frequency for males and females at *Tepe Hissar* independently by period. The frequencies of the traits were generally different among males (Figure 7.41 and Table 7.31). The males from Hissar I and II shared 22 traits. However, the peterogolar bridge, occipitomastoid ossicle, inferior parietal foramen, foramen spinosum open, and foramen vesalious (all 17%), condylar

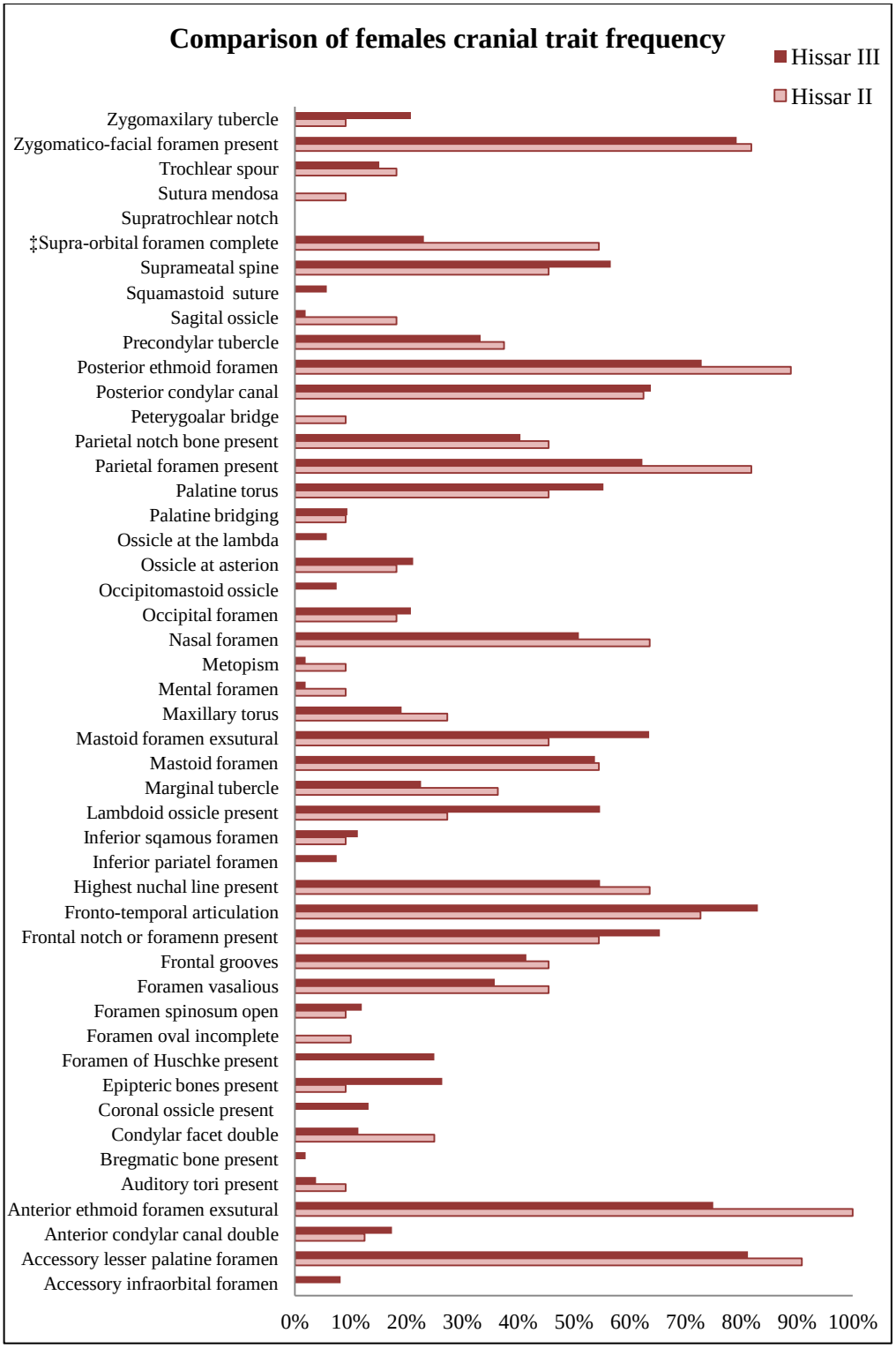
facet double (33%), anterior condylar canal double (50%), and supra-orbital foramen double (50%) were present in Hissar II males and absent in Hissar I males, but they continued with slight differences in frequency for Hissar III. On the other hand, foramen of Huschke, epipteric bone, and the zygomatic tubercle were present in Hissar I males, but completely absent in Hissar II; but also were seen among Hissar III males with frequencies of 11%, 16%, and 26%, respectively. The suprameatal spine, ossicle at asterion, mastoid foramen exsutural, and frontal grooves occurred more frequently in Hissar II than in Hissar I (Table7.31). Comparison between Hissar II and III showed that 33 traits which were common in Hissar II were retained in skulls from Hissar III (see above). However, there were 11 new cranial traits with low frequencies in Hissar III, including trochlear spur (1%), metopism (3%), supratrochlear notch (5%), sagittal ossicle (7%), foramen ovale incomplete (8%), mental foramen (8%), squamomastoid suture (8%), palatine bridging (8%), inferior squamous foramen (8%), coronal ossicle (11%), and accessory infraorbital foramen (14%). Statistical analysis showed a significant difference in fronto-temporal articulation (p=0.006) among males in Hissar II and III. The data show continuity in the frequency distribution of some traits over the three periods, and the appearance of new traits in later periods Hissar II and III.



‡ *Statistically significant differences: p≤0.05*

Fig 7.41. Comparison of male cranial trait frequency at Tepe Hissar, by period

Comparison between females showed that all 11 traits occurred in Hissar I, and were retained in Hissar II. However, since there was just one female dated to Hissar I, the frequency of traits for this period should be considered with caution. The females dated to Hissar II and III had 37 traits in common, varying in frequency. Compared to previous periods, eight new traits are apparent in Hissar III, including bregmatic bone (2%), ossicle at lambda (6%), inferior parietal foramen (8%), occipitomastoid ossicle (8%), foramen of Huschke (25%), coronal ossicle (13%), accessory infraorbital foramen (8%), and the squamomastoid suture (6%). The last three traits were also new among males in this period. There were three traits, including foramen ovale incomplete, sutura mendosa and peterygoalar bridge which were already present in Hissar II, but disappeared in Hissar III. However, statistical analysis showed a significant difference in supra-orbital foramen complete (p=0.035) among the females from Hissar II and III. The data indicate continuity in the prevalence rate of some traits in females from all periods, and the occurrence of new traits in II and III. The auditory tori and bregmatic bone had a low frequency among females (auditory tori:9% and 4% in II and III, and 2% for the bregmatic bone represented by one female in III), and none of the males had these traits. However, the supratrochlear notch was only seen in males from Hissar III (5%) and none of the females and males from other periods had this trait (insignificant).

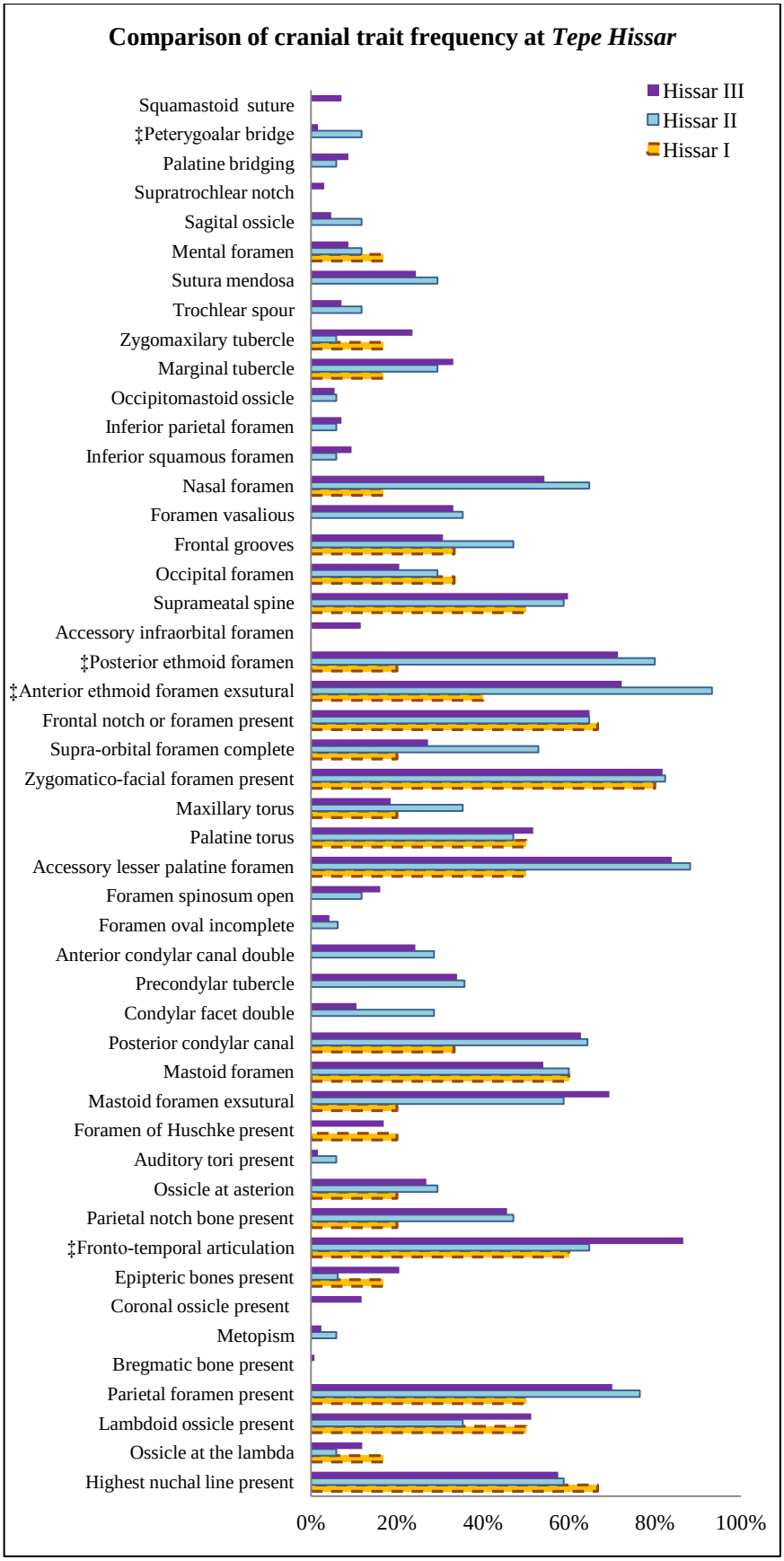


‡ *Statistically significant differences: p≤0.05*

Fig 7.42. Comparison of female cranial trait frequency at Tepe Hissar, by period

(iii) Comparison of Non-Metric Cranial Trait Frequency for each Trait between Periods, by Pooled Sex

When comparing cranial trait frequency for the three periods at *Tepe Hissar* with the sexes combined (Figure7.43), however, there were four traits that showed a significant difference statistically: the fronto-temporal articulation (p=0.028), anterior ethmoid foramen exsutural (p=0.05), posterior ethmoid foramen (p=0.033), and peterygoalar bridge (p=0.046). The fronto-temporal articulation was more frequent in Hissar III (87%) compared to Hissar II (65%) and Hissar I (60%), but the anterior ethmoid foramen exsutural was more prevalent in Hissar II (93%) than Hissar I (40%) and Hissar III (72%). The posterior ethmoid foramen was more frequent in Hissar II (80%). However, the peterygoalar bridge was absent in Hissar I, present with a higher frequency in Hissar II (12%), and lower in Hissar III (2%).



‡ *Statistically significant differences: p≤0.05*

Fig 7.43. Comparison of cranial trait frequency at Tepe Hissar, by period and the sexes pooled

7.4.2. Post-Cranial Non-Metric Trait Frequency

A total of 212 individuals were scored for 25 post-cranial non-metric traits, of which 12 individuals were from Hissar I, 28 were from Hissar II, and 172 were from Hissar III. Table 7.32 tabulates the frequency distribution of these traits by sex and period. This table also provides statistically significant differences when comparing females and males for each trait by period independently. Unfortunately, the Hissar I and II skeletons were incomplete and in a poor state of preservation for recording post-cranial non-metric traits. Therefore, due to very small sample size, the frequency of post-cranial traits, particularly for Hissar I, should be read with caution.

Table 7.32. Post-cranial non-metric trait frequency for Tepe Hissar, by sex and period

		Hissar I			**Hissar II**			**Hissar III**		
Code	**Variables**	*Male (n=6)*	*Female (n=6)*		*Male (n=11)*	*Female (n=17)*		*Male (n=84)*	*Female (n=88)*	
		A/O (%)	*A/O (%)*	***p***	*A/O (%)*	*A/O (%)*	*p*	*A/O (%)*	*A/O (%)*	***p***
1	*Allen's fossa*	1/4(25)	1/1(100)		3/7(43)	3/10(30)		24/64(37)	26/65(40)	
2	*Poirier's facet*	0/3(0)	-		2/6(33)	3/10(30)		25/62(40)	39/69(56)	
3	*Plaque*	3/3(100)	1/1(100)		4/7(57)	4/10(40)		40/67(60)	18/62(29)	‡
4	*Hypotrochanteric fossa*	1/4(25)	-		6/7(86)	3/10(30)	‡	28/67(42)	26/68(38)	
5	*Exostosis in trochanteric fossa*	0/3(0)	1/1(100)		4/7(57)	2/10(20)		33/65(51)	24/65(37)	
6	*Third trochanter*	0/3(0)	1/1(100)		0/6(0)	0/10(0)		3/60(5)	2/60(3)	
7	*Medial tibial squatting-facet*	0/2(0)	0/3(0)		0/5(0)	0/15(0)		2/64(3)	3/65(5)	
8	*Lateral tibial squatting-facet*	0/2(0)	1/3(33)		0/5(0)	6/15(40)		23/66(35)	24/69(35)	
9	*Supracondyloid process*	0/3(0)	0/4(0)		0/7(0)	0/14(0)		2/58(3)	1/48(2)	
10	*Septal-aperture*	0/3(0)	2/5(40)		4/8(50)	11/15(73)		20/61(33)	29/53(55)	‡
11	*Acetabular crease*	-	-		0/1(0)	0/2(0)		5/11(45)	7/17(41)	
12	*Preauricular-sulcus*	-	-		0/1(0)	0/2(0)		0/10(0)	1/15(7)	
13	*Accessory sacral facets*	-	-		0/1(0)	0/2(0)		3/11(27)	1/15(7)	
14	*Acromial articular facet*	-	-		1/1(100)	-		0/7(0)	0/7(0)	
15	*Suprascapular foramen*	-	-		0/2(0)	0/2(0)		1/13(8)	1/9(11)	
16	*Circumflex sulcus*	-	-		1/3(33)	1/2(50)		8/15(53)	6/13(46)	
17	*Vastus notch*	-	-		-	1/1(100)		4/6(67)	8/9(89)	
18	*Vastus fossa*	-	-		-	1/1(100)		5/7(71)	5/9(56)	
19	*Emarginate patella*	-	-		-	0/1(0)		1/7(14)	1/10(10)	
21	*Medial talar facet*	-	-		-	1/1(100)		2/2(100)	3/3(100)	
22	*Lateral talar extension*	-	-		1/1(100)	1/1(100)		6/6(100)	3/3(100)	
23	*Inferior talar articular surface*	-	-		-	-		9/9(100)	4/4(100)	
24	*Anterior calcaneal facet double*	-	-		-	1/1(100)		12/12(100)	5/5(100)	
25	*Anterior calcaneal facet absent*	-	-		-	1/1(100)		2/2(100)	1/1(100)	
26	*Peroneal tubercle present*	-	-		1/1(100)	-		12/12(100)	5/5(100)	

‡ Statistically significant differences at P≤0.05 value. A/O: affected/observed

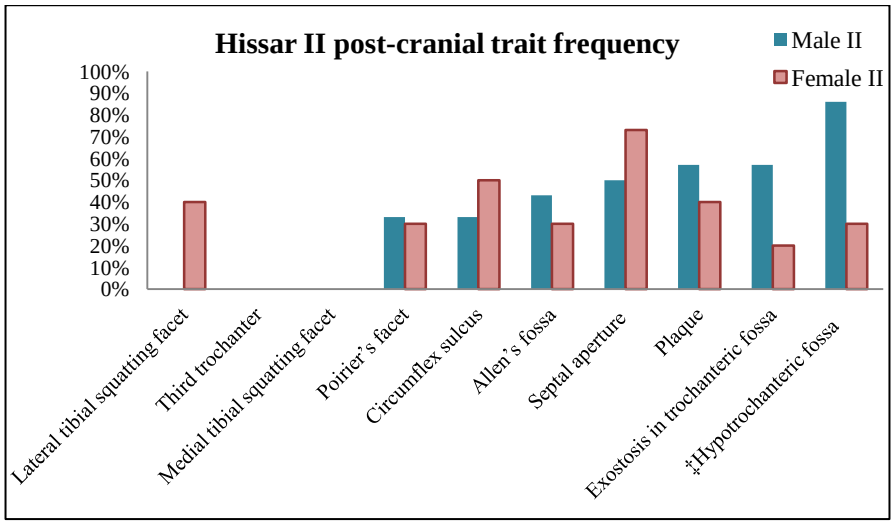
(i) Comparison of Post-Cranial Non-Metric Trait Frequency by Period for each Trait, by Sex

(a) Hissar I

The Allen's fossa (25%), plaque (25%) and hypotrochanteric fossa (100%) appeared more frequently in males (Table7.32). The lateral tibial squatting-facet and septal-aperture were present in females with frequencies of 33% and 40%, respectively, but they were absent in males. However, as mentioned before, one must consider the small sample size from this period.

(b) Hissar II

Table 7.32 and Figure 7.44 illustrate the frequency of post-cranial non-metric traits for Hissar II individuals. The males had a higher frequency of hypotrochanteric fossa (86%), plaque (57%), exostosis in trochanteric fossa (57%), Allen's fossa (43%) and Poirier's facet (33%), compared to females with frequencies of 20%, 40%, 20%, 43%, and 30%, respectively, and the difference in males and females for the hypotrochanteric fossa was statistically significant (p=0.024). The septal-aperture (73%) and circumflex sulcus (50%) was more frequent in females compared to males (50% and 33%, respectively). The lateral tibial squatting-facet (40%) was presented in females but absent in males (0%). There were no statistically significant differences for the rest of the skeletal traits for both sexes.



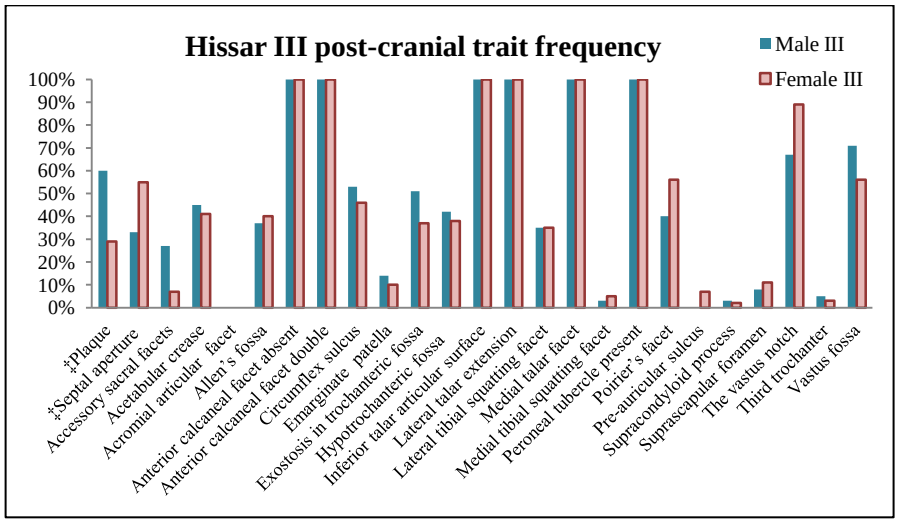
‡ *Statistically significant differences: p≤0.05*

Fig 7.44. Hissar II: Post-cranial non-metric trait frequency, by sex

(c) Hissar III

Table 7.32 and Figure7.45 show that males and females had the highest frequency for six traits (100%): the peroneal tubercle, medial talar facet, inferior talar articular

surface, anterior calcaneal facet double, anterior calcaneal facet absent and lateral talar extension. The vastus fossa (71%) and vastus notch (67%) in males were the second and the third most frequent traits, but in females the vastus fossa was less frequent (56%) and the vastus notch was more frequent (89%) compared to males. The frequencies of plaque (60%), circumflex sulcus (53%), exostosis in trochanteric fossa (51%), acetabular crease (45%), hypotrochanteric fossa (42%), accessory sacral facets (27%) and emarginated patella (14%) were higher in males compared to females (29%, 46%, 37%, 41%, 38%, and 7%, respectively). There was a significant difference in the frequency of plaque (p=0.000) for males and females. However, the occurrence of Poirier's facet (56%), Allen's fossa (40%), and septal-aperture was higher in females (55%) compared to males, with frequencies of 40%, 37% and 33%, respectively; the difference in the frequency of septal-aperture was statistically significant (p=0.018). The medial tibial squatting-facet, supracondyloid process and the third trochanter were the least frequent (between 2-5%) traits in both sexes. The preauricular-sulcus was present in females (7%) but absent in males.



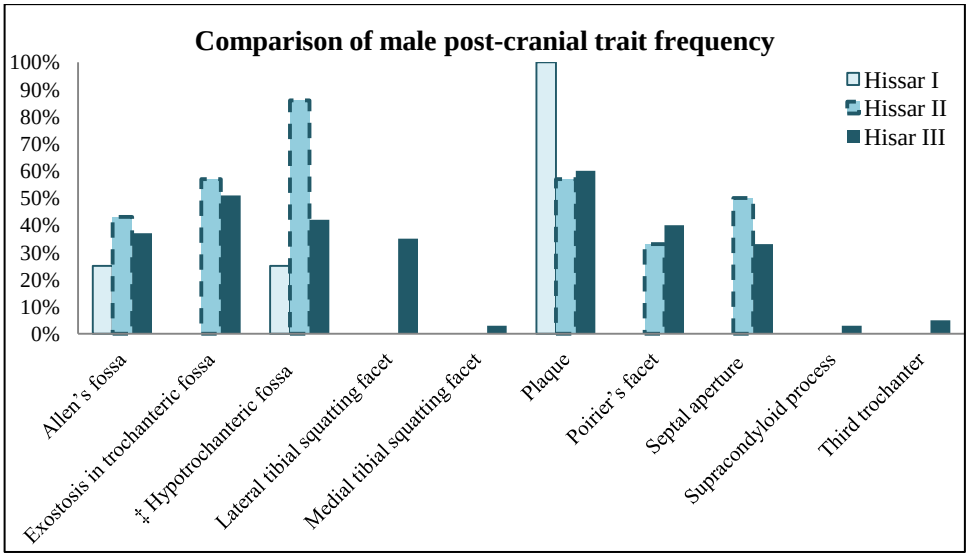
‡ *Statistically significant differences: p≤0.05*

Fig 7.45. Hissar III: Post-cranial non-metric trait frequency, by sex

(ii) Comparison of Post-Cranial Non-Metric Trait Frequency Between Periods for each Trait Independently by Sex

Figure 7.46 shows the frequency distributions of 10 common skeletal traits among males at *Tepe Hissar*. The acetabular crease (45%), accessory sacral facets (27%), suprascapular foramen (8%), third trochanter (5%), medial and lateral tibial squatting-facets (3% and 35%), and the supracondyloid process (3%) were presented in Hissar III, but absent in Hissar II. The frequencies of hypotrochanteric fossa (86%), septal-aperture

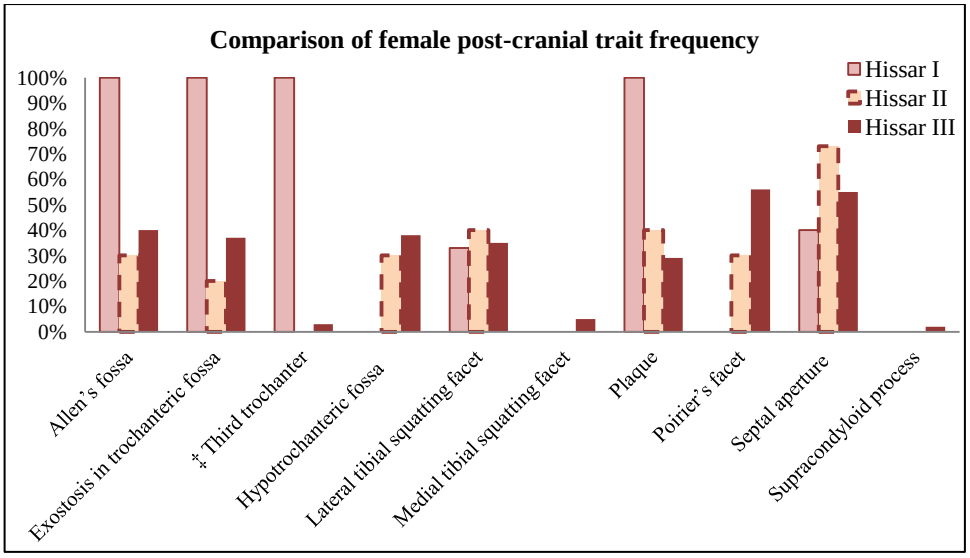
(50%), Allen's fossa (43%), and exostosis in the trochanteric fossa (57%) were higher in Hissar II compared to Hissar III (42%, 33%, 37%, and 51%, respectively). The frequency of Allen's fossa and the hypotrochanteric fossa was 25% for both in Hissar I (Table 7.33). However, none of these differences, except for the hypotrochanteric fossa (p=0.050), were statistically significant in males.



‡ *Statistically significant differences: p≤0.05*

Fig 7.46. Comparison of male 10 post-cranial non-metric traits frequencies at Tepe Hissar, by period

Figure 7.47 shows the frequency of 10 common skeletal traits in females at *Tepe Hissar*. The frequencies of septal-aperture (73%) and lateral tibial squatting-facets (40%) were higher in Hissar II compared to Hissar I (40% and 33%) and Hissar III (55% and 35%), respectively (Table 7.32). At Hissar III there was a higher frequency for Allen's fossa (40%), Poirier's facet (56%), hypotrochanteric fossa (38%) and exostosis in the trochanteric fossa (37%) compared to Hissar II (20-30%). The medial tibial squatting-facet and supracondyloid process were not present in females in Hissar II and I, but they were recorded with a low frequency (2-5%) in Hissar III. In addition, the acetabular crease (41%), suprascapular foramen (11%), emarginated patella (10%), preauricular-sulcus (7%), accessory sacral facets (7%), and third trochanter (3%) were present in Hissar III, but absent in Hissar II (0%). Allen's fossa, exostosis in the trochanteric fossa, third trochanter and plaque were all present in the one female in Hissar I, but this represents just one individual. Nevertheless, none of these differences, except the third trochanter (p=0.000), showed statistical significance between the periods.



‡ *Statistically significant differences: p≤0.05*

Fig 7.47. Comparison of 10 female post-cranial non-metric trait frequencies at Tepe Hissar, by period

The preauricular-sulcus (7%) was just present in females from Hissar III, but absent among the females from the other periods, as well as males in all periods. However, some traits, including accessory sacral facets, acetabular crease, medial tibial squatting-facet, supracondyloid process, and suprascapular foramen were present in both sexes in Hissar III but not in Hissar II.

(iii) Comparison of Post-Cranial Non-Metric Trait Frequency for each Trait Between Periods, by Pooled Sex

Figure 7.48 shows the frequency of post-cranial non-metric traits at *Tepe Hissar* by pooled sex, showing that the frequency between the traits varied in each period as well as between periods. There were new traits that occurred, for example in Hissar III, but these differences were not statistically significant. The frequency of septal-aperture (65%) and hypotrochanteric fossa (53%) was higher in Hissar II compared to Hissar III (43% and 40%, respectively), and was the lowest in Hissar I (25%). However, the lateral tibial squatting-facet (35%), exostosis in the trochanteric fossa (44%), and Poirier's facet (49%) had a higher frequency in Hissar III, compared to Hissar II (30%, 35%, and 31%, respectively) and Hissar I (20%, 25%, and 0%, respectively). The supracondyloid process, accessory sacral facets, acetabular crease, medial tibial squatting-facet, and preauricular-sulcus were presented in Hissar III, but absent in Hissar I and II. The emarginate patella (12%) and suprascapular foramen (9%) were only recorded in individuals from Hissar III. Since the sample size from Hissar III was

larger compared to previous periods, there was more chance of seeing variation in trait frequency.

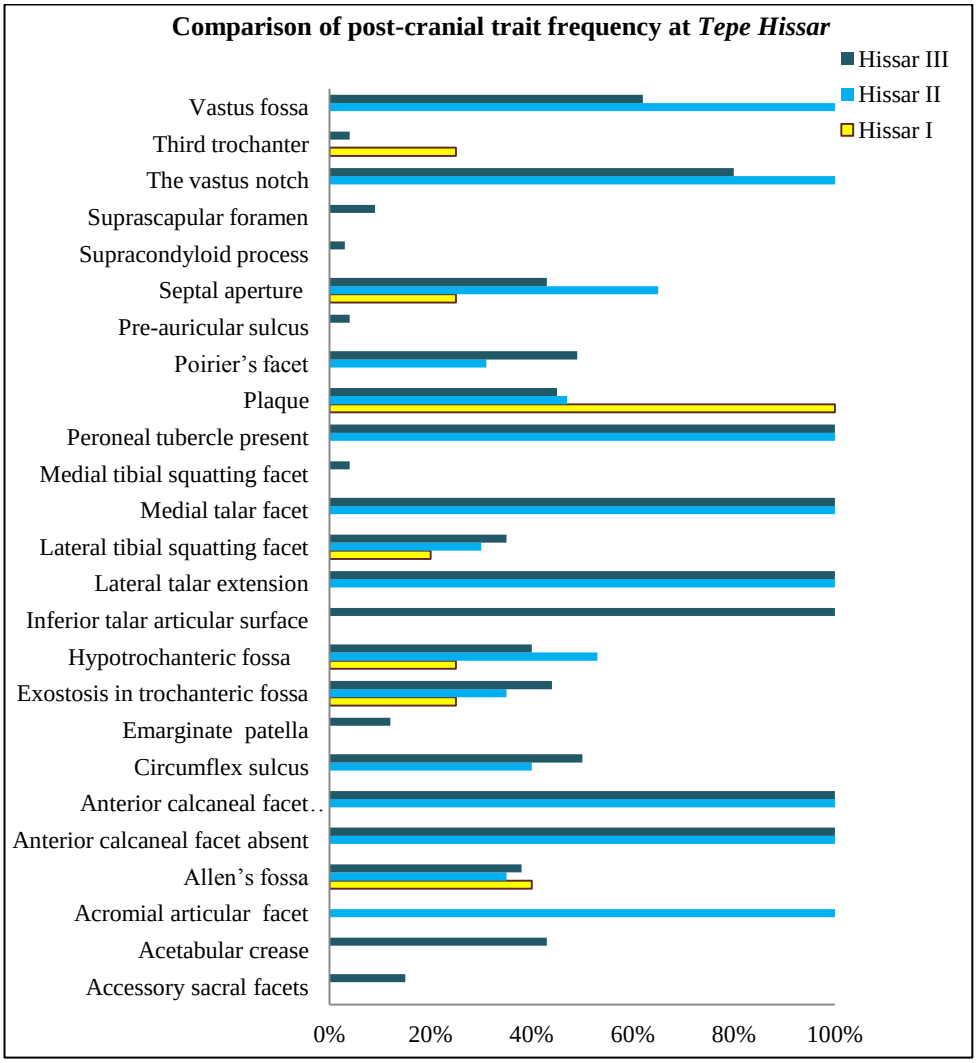


Fig 7.48. Comparison of post-cranial non-metric trait frequency at Tepe Hissar, by period and the sexes pooled

7.4.3. Dental Non-Metric Trait Frequency

A total of 141 individuals (63 female and 78 male) were examined for 26 dental non-metric traits, of which 15 were from Hissar I, 17 were from Hissar II, and 109 from Hissar III. Table 7.33 presents the frequency distribution of dental non-metric traits in the *Tepe Hissar* population by sex and period. Unfortunately, due to post-mortem damage and fragmentation, heavy attrition, ante-and post-mortem tooth loss, and pathology, many teeth were not well preserved for observation, or in good condition for dental non-metric trait studies. This reduced the number of observable traits for each individual and the number of individuals for each trait that could be observed. Therefore, the frequency of traits should be read with caution.

Table 7.33. Dental non-metric trait frequency for Tepe Hissar, by sex and period

	Hissar I			Hissar II			Hissar III		
	Male (n=8)	*Female (n=7)*		*Male (n=7)*	*Female (n=10)*		*Male (n=63)*	*Female (n=46)*	
Variables	*A/O (%)*	*A/O (%)*	***p***	*A/O (%)*	*A/O (%)*	***p***	*A/O (%)*	*A/O (%)*	***p***
Winging UI1	1/4(25)	0/2(0)		0/2 (0)	0/2 (0)		0/11(0)	0/11(0)	
Shoveling UI1	2/4(50)	0/2(0)		0/2(0)	1/2(50)		3/12(25)	6/16(50)	
Labial curvature UI1	4/4(100)	1/2(50)		1/2(50)	0/3(0)		4/12(33)	8/16(50)	
Interruption groove UI2	0/4(0)	0/2(0)		0/2(0)	1/3(33)		0/12(0)	2/15(13)	
Tuberculum dentale UI2	1/4(25)	0/1(0)		1/4(25)	1/4(25)		3/17(18)	4/17(23)	
Mesial ridge UC	0/5(0)	0/2(0)		0/4(0)	0/6(0)		0/19(0)	0/19(0)	
Distal accessory ridge UC	0/5(0)	1/2(50)		0/5(0)	0/6(0)		0/19(0)	0/20(0)	
Distosagital ridge UPM1	0/5(0)	0/2(0)		0/5(0)	0/7(0)		0/24(0)	0/25(0)	
Metacone (cusp3)UM3	5/5(100)	2/2(100)		6/6(100)	6/7(86)		29/31(93)	25/26(96)	
Hypocone (cusp4)									
UM1	5/5(100)	2/2(100)		5/5(100)	7/7(100)		26/27(96)	26/27(96)	
UM2	3/4(75)	1/2(50)		4/6(67)	6/7(86)		16/32(44)	15/30(50)	
UM3	3/5(60)	1/2(50)		2/6(33)	5/7(71)		12/28(43)	13/27(48)	
Metaconule (cusp5)									
UM1	0/5(0)	1/2(50)		0/6(0)	1/7(14)		2/33(6)	3/29(10)	
UM2	0/4(0)	1/2(0)		0/6(0)	1/7(14)		2/33(6)	2/31(6)	
UM3	0/5(0)	1/2(50)		0/6(0)	1/7(14)		1/30(3)	2/28(7)	
Carabelli's trait UMs	2/5(40)	0/2(0)		1/6(17)	2/7(29)		7/35(20)	6/31(19)	
Parastyle UM3	0/5(0)	0/2(0)		0/6(0)	0/7(0)		2/35(6)	4/31(13)	
Enamel extension UM1	0/5(0)	1/2(50)		2/6(33)	1/7(14)		10/34(29)	12/31(39)	
Congenital absence UM3	1/5(20)	0/2(0)		1/6(17)	0/7(0)		10/38(26)	8/32(25)	
Shoveling LI1	0/5(0)	1/4(25)		0/3(0)	2/4(50)		2/18(11)	4/21(19)	
Congenital absence LM3	2/8(25)	3/6(50)		1/3(33)	1/9(11)		4/46(15)	4/38(10)	
Lingual cusp variation									
LPM1	2/7(29)	3/6(50)		2/3(67)	2/8(25)		11/40(27)	12/35(34)	
LPM2	6/8(75)	5/6(83)		3/3(100)	6/8(75)		28/39(72)	21/35(60)	
X-Groove pattern LM1	2/5(20)	0/5(0)		2/2 (100)	3/7(43)		12/27(44)	8/27(30)	
Y-Groove pattern LM1	3/5(60)	5/5(100)		0/2(0)	4/7(57)		14/27(52)	19/27(70)	
+-Groove pattern LM1	0/5(0)	0/5(0)		0/2(0)	0/7(0)		1/27(4)	0/27(0)	

X-Groove pattern LM2	2/5(40)	4/5(80)	2/2 (100)	3/5(60)	22/35(63)	18/30(60)	
Y-Groove pattern LM2	1/5(20)	1/5(20)	0/2(0)	1/5(20)	10/35(29)	7/30(23)	
+-Groove pattern LM2	2/5(40)	0/5(0)	0/2(0)	1/5(20)	3/35(9)	5/30(17)	
X-Groove pattern LM3	1/4(25)	1/3(33)	2/2(100)	2/5(40)	19/27(70)	15/26(58)	
Y-Groove pattern LM3	2/4(50)	2/3(67)	0/2(0)	1/5(20)	6/27(22)	9/26(35)	
+-Groove pattern LM3	1/4(25)	0/3(0)	0/2(0)	2/5(40)	2/27(7)	2/26(8)	
Distal trigonid crest LM3	0/7(0)	1/4(25)	0/3(0)	0/8(0)	2/40(5)	2/36(6)	
Protostylid LM3	1/7(14)	0/4(0)	0/3(0)	2/9(22)	7/40(17)	7/26(19)	
Cusp 5 LM1	2/8(25)	2/5(40)	2/3(67)	6/9(67)	11/41(27)	17/37(46)	
Cusp 5 LM2	0/8(0)	0/5(0)	0/3(0)	1/9(11)	1/41(2)	1/37(3)	
Cusp 5 LM3	2/7(29)	1/4(25)	2/3(67)	3/9(33)	6/40(15)	12/36(33)	
Cusp 6 LM3	1/7(14)	0/4(0)	0/3(0)	1/9(11)	2/40(5)	2/36(6)	
Cusp 7 LM3	1/7(14)	0/4(0)	0/3(0)	0/9(0)	2/40(5)	3/36(8)	
Enamel extension LM1	1/8(12)	1/5(20)	1/3(33)	2/9(22)	2/41(5)	8/37(22)	0.027‡
Cusp number							
LM1 (5+)	0/7(0)	0/5(0)	0/3(0)	1/8(12)	1/35(3)	0/33(0)	
LM2 (3)	0/7(0)	0/5(0)	0/3(0)	1/7(14)	2/38(5)	0/32(0)	
LM2 (5+)	0/7(0)	0/5(0)	0/3(0)	1/7(14)	1/38(3)	2/32(6)	
LM3 (3)	0/5(0)	0/3(0)	0/3(0)	1/7(14)	5/31(16)	1/28(4)	
LM3 (5+)	2/5(40)	0/3(0)	2/3(67)	3/7(43)	6/31(19)	10/28(36)	

‡Statistically significant differences at $P \leq 0.05$ value. A/*O, affected/observed*

(i) Comparison of Dental Non-Metric Trait Frequency by Period for each Trait, by Sex

(a) Hissar I

Table 7.33 and Figure 7.49 show the differences in dental trait frequency among males and females from Hissar I. The males showed a relatively higher prevalence of labial curvature UI1 (100%), hypocone UM2 (75%), and cusp 5 LM3 (29%) compared to females (50%, 50%, and 25%, respectively). Females had a higher frequency for lingual cusp variation LPM1(50%) and LPM2 (83%), X-groove pattern LM2 (80%) and LM3 (33%), Y-groove pattern LM1 (100%), LM3 (67%), congenital absence of LM3, enamel extension LM1 (20%), and cusp 5 LM1 (40%) than males. Some traits, for example Carabelli's trait (40%), protostylid LM3 (14%), shovelling UI1(50%), +-groove pattern on LM2(40%) and LM3 (25%), cusp 6 and 7 LM3 (14%), and congenital absence UM3 (20%) were seen in males but were absent in females (Table7.33). On the other hand, distal accessory ridge UC (50%), metaconule UM1(50%), enamel extension UM1 (50%), shovelling LI1 (25%), and distal trigonid crest LM3 (25%) were present in females but absent in males. However, one should consider the small sample size of individuals for this period. Nevertheless, statistical tests showed no significant differences in frequency between the sexes.

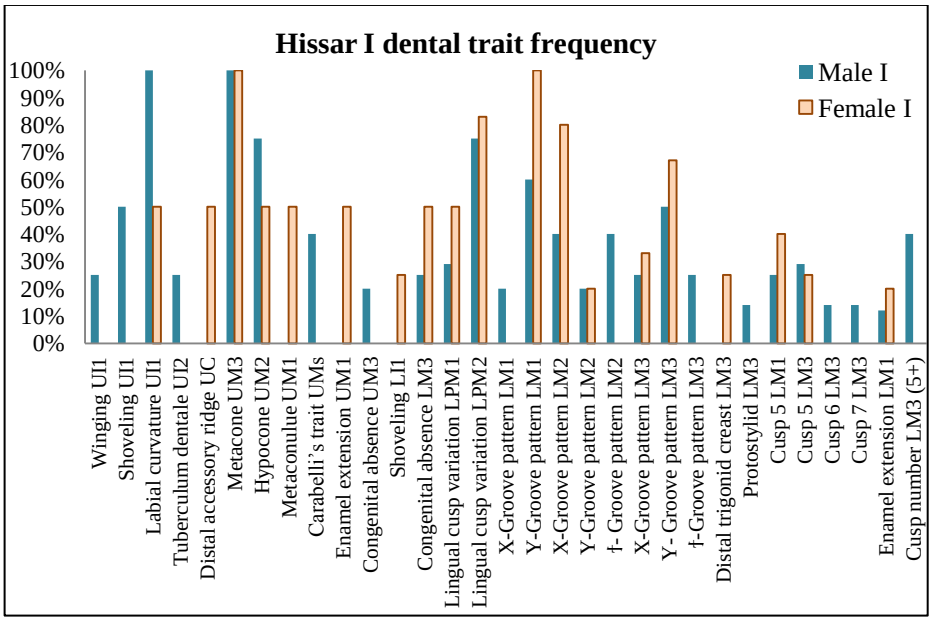


Fig 7.49. Hissar I: Dental non-metric trait frequency, by sex

(b) Hissar II

Figure 7.50 shows that dental non-metric traits frequencies were generally different among males and females from Hissar II (insignificant) (Table 7.33). Females showed more variety in the number of dental traits compared to the males as they did

for cranial traits. Lingual cusp variation LPM2 (100%) and LPM1(67%), X-groove pattern LM1, LM2 and LM3, metacone UM3, hypocone UM1 all had frequencies of 100%, with enamel extension LM1 and UM1 (both 33%), cusp 5 LM3 and 5 LM1 (both 67%), and congenital absence LM3 (33%) present in higher frequencies in males compared to females (Table 7.33). On the other hand, in females the frequencies for hypocone UM2 (86%), and Carabelli's cusp (29%) were higher compared to males (67% and 17%, respectively). Congenital absence of UM3 (17%) and labial curvature UI1 (50%) were recorded in males but were absent in females. However, there were some traits, for example shovelling LI1 and UI1 (both 50%), protostylid LM3 (22%), 3 and 5 cusps LM2 (both 14%) and others (Table 7.33) present in females but not in males. However, the number of individuals available for observation of each trait was small and therefore the frequency should be viewed with caution.

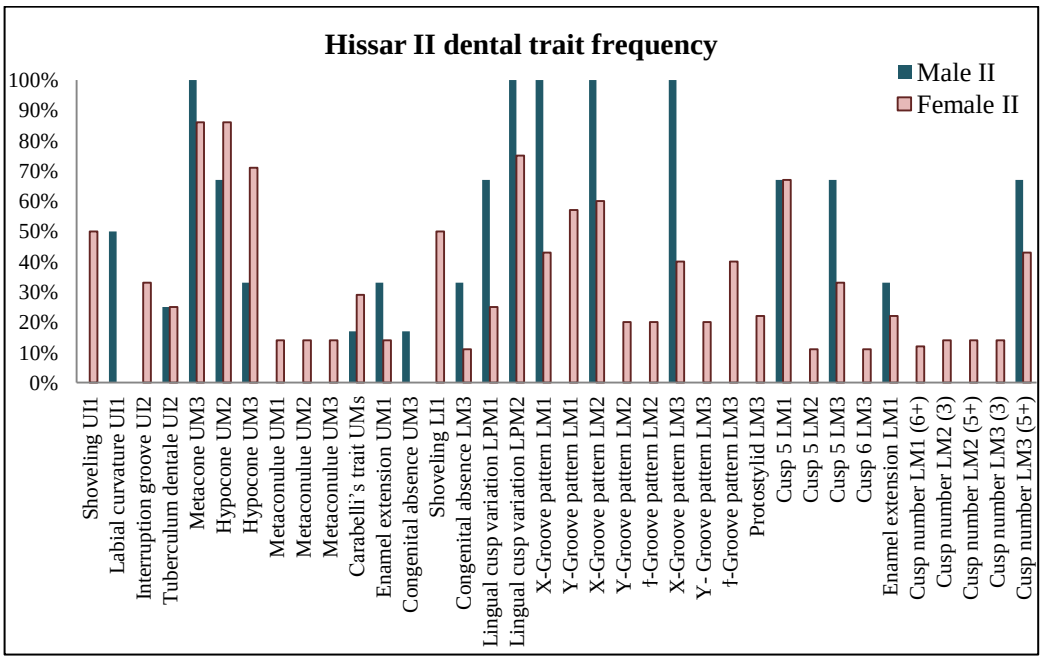


Fig 7.50. Hissar II: Dental non-metric trait frequency, by sex

(c) Hissar III

Figure 7.51 illustrates the frequencies for dental non-metric traits for Hissar III. Lingual cusp variation LPM2 (72%), X-groove pattern LM3 (70%), LM2 (63%), and LM1 (44%), 3 cusp LM3 (16%), and congenital absence of LM3 (15%) were higher in males than females (60%, 58%, 60%, 30%, 4%, and 10%, respectively) (Table 7.33). The 3 cusp LM2, +-groove pattern LM1 and 6 or more cusps LM1 were presented at a low frequency (3-5%) among males. However, these traits were completely absent in females. Females had a higher frequency for Y-groove pattern LM1 (70%) and LM3 (35%), shoveling UI1 (50%), hypocone UM2 (50%), parastyle UM3 (13%), and enamel

extension LM1 (22%) and UM1 (39%) compared to males (52%, 22%, 25%, 44%, 6%, 5%, and 29%, respectively). None of these differences between the sexes, except for enamel extension LM1 (p=0.027), were statistically significant.

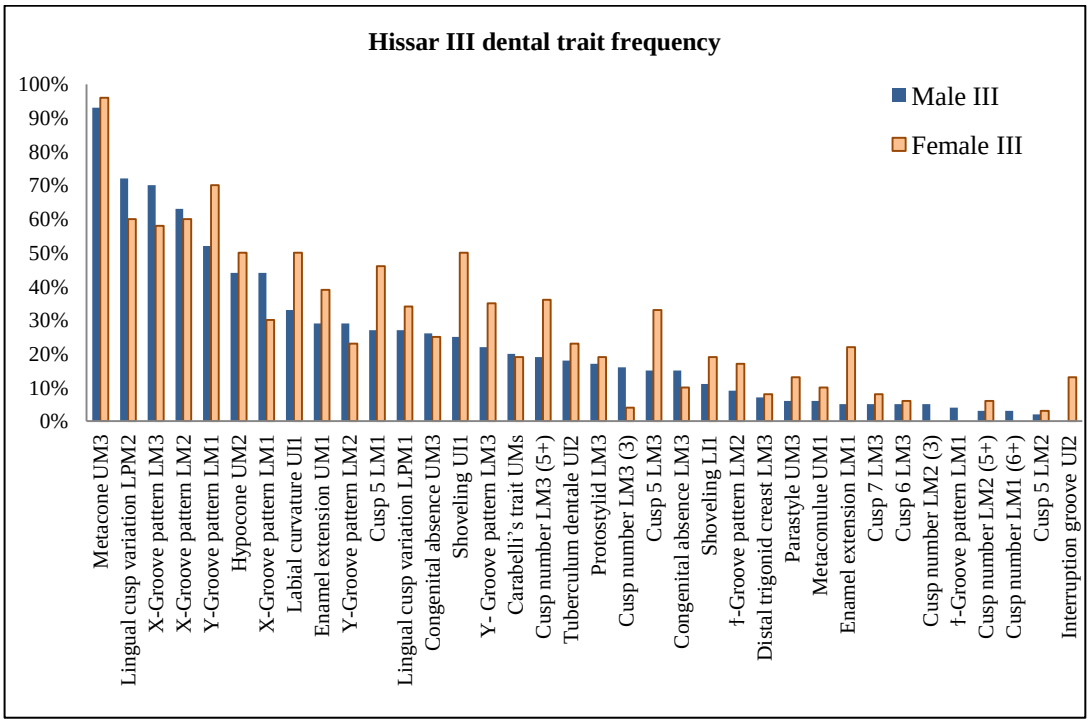


Fig 7.51. Hissar III: Dental non-metric trait frequency, by sex

(ii) Comparison of Dental Non-Metric Trait Frequency Between Periods for each Trait Independently by Sex

Figure 7.52 compares the frequency of 23 commonly observed dental traits between males from the three periods at *Tepe Hissar.* The frequencies were generally different among males and some traits were present in one group while absent in other groups cusp 6 and 7 LM3(14%), protostylid LM3(14%), Y-groove pattern LM2 (14%), LM1(43%), and LM3(40%), +-groove pattern LM2(29%) and LM3(20%), and shovelling UI1(50%) were recorded in Hissar I but were absent in Hissar II, while in Hissar III they were present but with slight differences in frequency. Carabelli's trait was more frequent in Hissar I(40%) compared to Hissar II(17%) and III(20%). People in Hissar II showed a higher prevalence for X-grooves lower molars (100%), hypocone UM2, 5 cusps LM3, lingual cusp variation LPM1, cusp 5 LM1 and 5 LM3 (67% for all five traits) , and a lower frequency for hypocone UM3(33%), Carabelli's trait(17%), and congenital absence UM3(17%) compared to Hissar I and III (see Table 7.33). The data from Hissar III exhibit a lower frequency of tuberculum dental UI2 (18%), enamel extension LM3 (5%), congenital absence LM3 (15%), cusp 5 LM3(15%) and 5 or more

cusps in LM3 than Hissar II. Shovelling LI1, metaconule UM1, UM2, and UM3, and parastyle UM3 were present at a low frequency (2-16%) in Hissar III but were completely absent in the previous periods. However, statistical analysis did not show any significant differences in the occurrence of dental non-metric traits between males at *Tepe Hissar*.

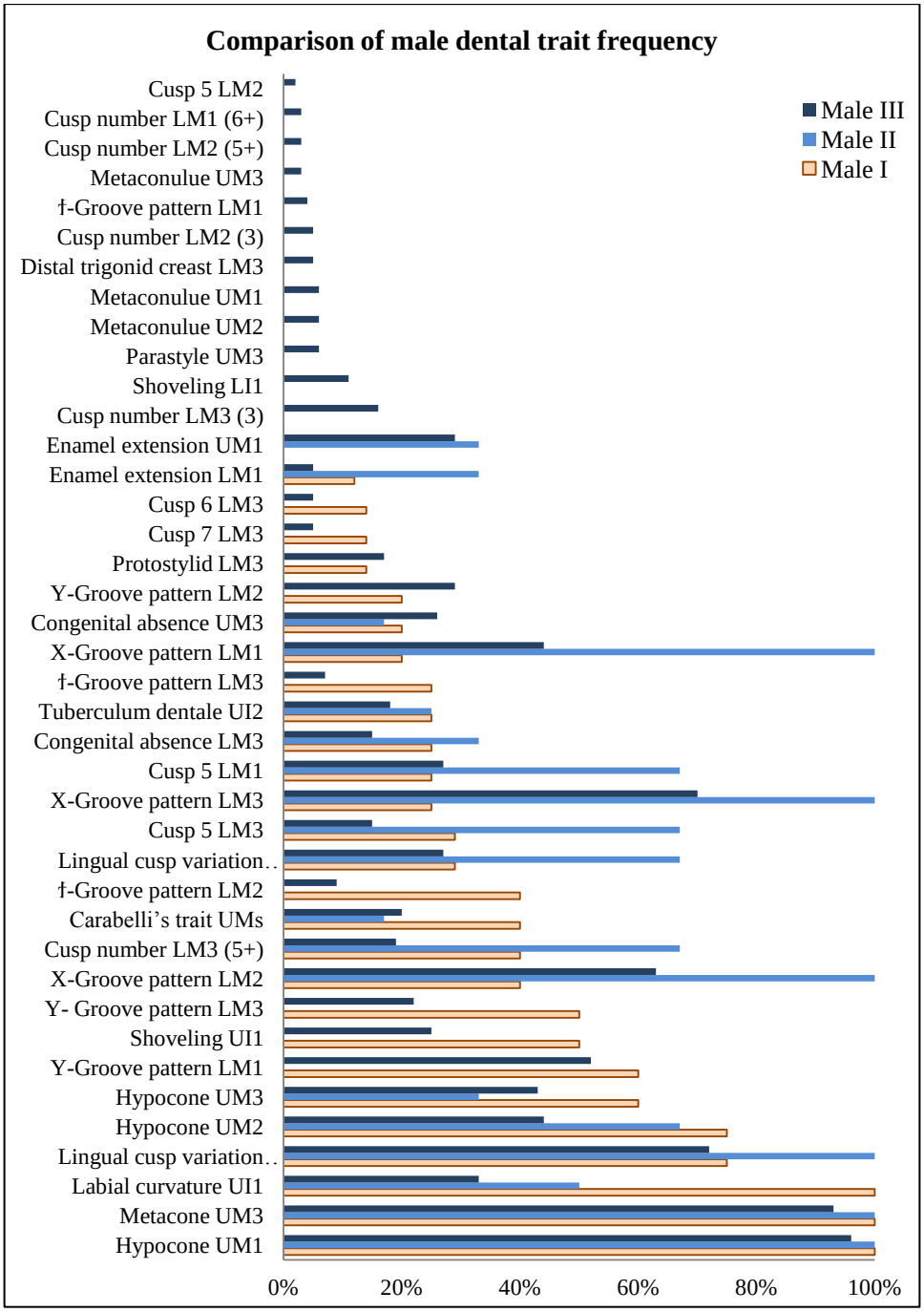
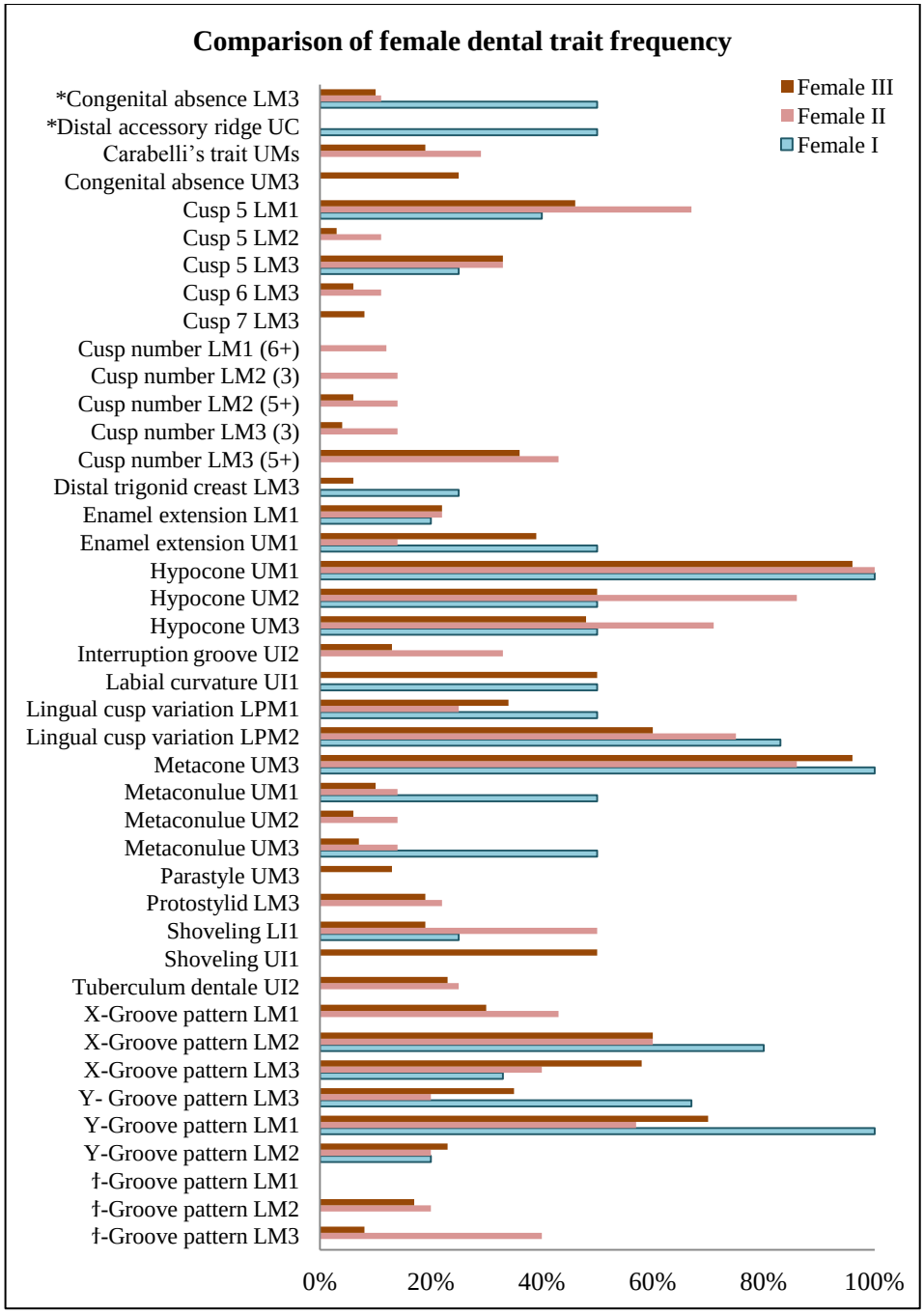


Fig 7.52. Comparison of male dental non-metric trait frequency at Tepe Hissar, by period

Figure 7.53 compares the distribution of dental non-metric traits among females at *Tepe Hissar*. Hypocone UM1 and metacone UM3 presented at a high frequency (100%)

in all three periods, but hypocone UM2 (86%) and UM3 (71%) were more frequent in Hissar II compared to the other periods. Shoveling LI1 was less frequent in Hissar III (19%) than Hissar II (50%) and Hissar I (25%), but shovelling UI1 was presented in Hissar III (50%) and was totally absent in previous periods. Carabelli's cusp was less frequent in Hissar III (19%) compared to Hissar II (29%), but was absent in Hissar I (0%). Congenital absence UM3 (25%), cusp 7 on LM3 (8%), parastyle UM3 (13%), lower C and PM1 rotation (8%), and shovelling UI1 (50%) were present in Hissar III but not for previous periods. Both in Hissar II and III the number of traits with frequencies less than 50% were predominant which might indicate many people from different places. However, statistical analysis showed a significant difference in congenital absence LM3 (p=0.04) and distal accessory ridge UC (p=0.001) expression between females from different periods at this site.



** Statistically significant differences: p≤0.05*

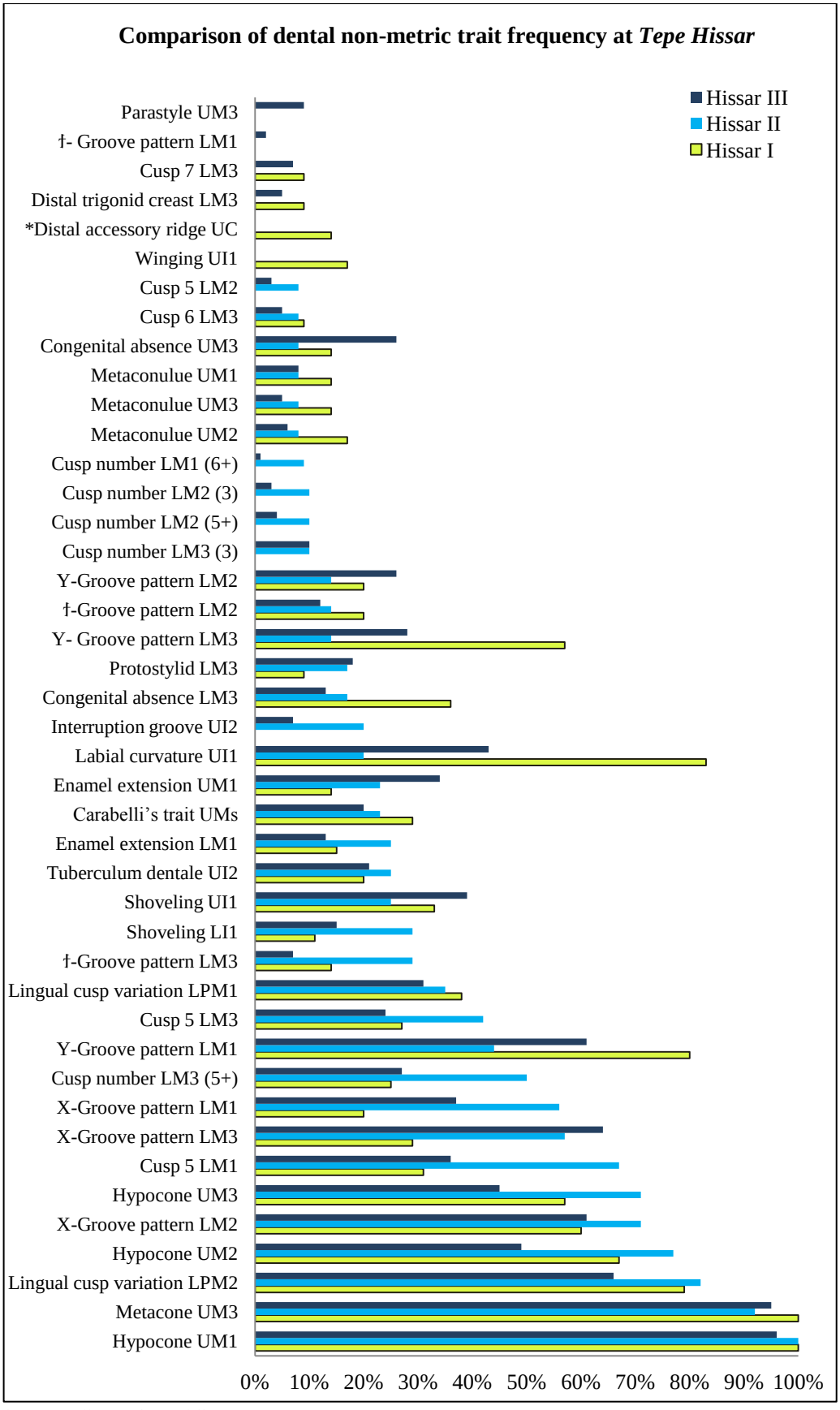
Fig 7.53. Comparison of female dental non-metric trait frequency at Tepe Hissar, by period

(iii) Comparison of Dental Non-Metric Trait Frequency for each Trait Between Periods, by Pooled Sex

The majority of the first molars in people from Hissar I and III had groove type 'Y' with frequencies of 80% and 61%, respectively, but in Hissar II the pattern 'X' was predominant (56%). In the second molars the pattern 'X' was more frequent in all periods and Hissar II had the highest frequency (71%). In the third molars the pattern 'X' was more common in Hissar II (57%) and III (64%), but the groove 'Y' type was

more frequent (57%) in Hissar I. The frequency of the '+' groove pattern in UM2 (12%) and UM3 (7%) in Hissar III was lower than for previous periods (Figure 7.54).

The frequency of metacone(100%), labial curvature UI1(83%), congenital absence UM3 (14%), and shoveling UI1(33%) decreased in Hissar II when compared to Hissar I, and there was an increase in the frequency of these traits in Hissar III. The hypocone was more frequent than the metaconule in all periods, and Hissar III showed a relatively lower frequency in both hypocone and metaconule than Hissar II. Carabelli's trait UMs and congenital absence LM3 were present at a higher frequency in Hissar I (29%, 36%) than Hissar II(23%,17%) and Hissar III(20%13%). However, the frequency of protostylid LM3 increased through time from 9% in Hissar I to 17% and 18% in Hissar II and III respectively. The distal accessory ridge UC (14%) (p=0.023) and winging UI1(17%) were seen in Hissar I but were absent in the later periods. The interruption groove UI, 6 or more cusps in LM1, cusp 5 in LM2, 3 cusps in LM2 and LM3, 5 or more cusps in LM2, and cusp 5 in LM2 were absent in Hissar I, but were present in Hissar II with frequencies between 8% and 20%, and Hissar III (but with lower frequencies of between 1% and 10%). The parastyle UM3 (9%) and +-groove pattern LM1(2%) were present in Hissar III but absent in Hissar I and II.



** Statistically significant differences: p≤0.05*

Fig 7.54. Comparison of dental non-metric trait frequency at Tepe Hissar, by period and pooled sex

7.5. Stress and Disease Profiles: Abnormal Variations

7.5.1. Hissar I

(i) Metabolic disease profile

Table 7.34 and Figure 7.55 demonstrate the metabolic disease profile for Hissar I by sex. The prevalence of metabolic disease in total was higher among females than males. Nineteen of the 28 individuals from this period could be observed for metabolic disease, and nine of those showed pathological bone changes consistent with this condition (47.4%). Females had a higher prevalence of metabolic disease (67%) than males (40%) (insignificant). There were six individuals (5 male,1 female) with an orbit preserved for study of CO. The percentage of females with CO was higher ((1/1)100%) than for males ((1/5)20%), but there was only one female to observe (insignificant). The same situation for PH was found. Four of the five males were affected (80%).

Table 7.34. Hissar I: Metabolic disease profile by sex

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	***X2***	***P***
Cribra Orbitalia	1/5	20%	1/1	100%	-	-	2/6	33%	2.4	0.333
Porotic Hyperostosis	4/5	80%	0/1	0%	-	-	4/6	67%	2.4	0.333
Vitamin C Deficiency	0/10	0%	0/6	0%	0/3	0%	0/19	0%	-	-
Total Vitamin D Deficiency	3/7	43%	3/5	60%	1/3	33%	7/15	48%	0.612	0.736
Residual Rickets/Osteomalacia	2/6	33%	3/5	60%	1/3	33%	6/14	43%	0.933	0.627
Osteopenia/Osteoporosis	1/10	10%	3/6	50%	1/3	33%	5/19	26%	3.185	0.203
Total Metabolic Diseases	4/10	40%	4/6	67%	1/3	33%	9/19	47%	1.351	0.509

P≤0.05

Comparing the prevalence of vitamin C deficiency, there was no evidence of this deficiency. However, almost 48% of Hissar I individuals showed bone changes indicative of vitamin D deficiency. The percentage of vitamin D deficiency was 17% higher among females than males (insignificant). The prevalence rate for residual rickets/or osteomalacia in females (60%) was higher than in males (33%) (insignificant). Nineteen individuals were observed for osteopenia/osteoporosis, and almost 26% were affected. However, females were affected 40% more than males (insignificant).

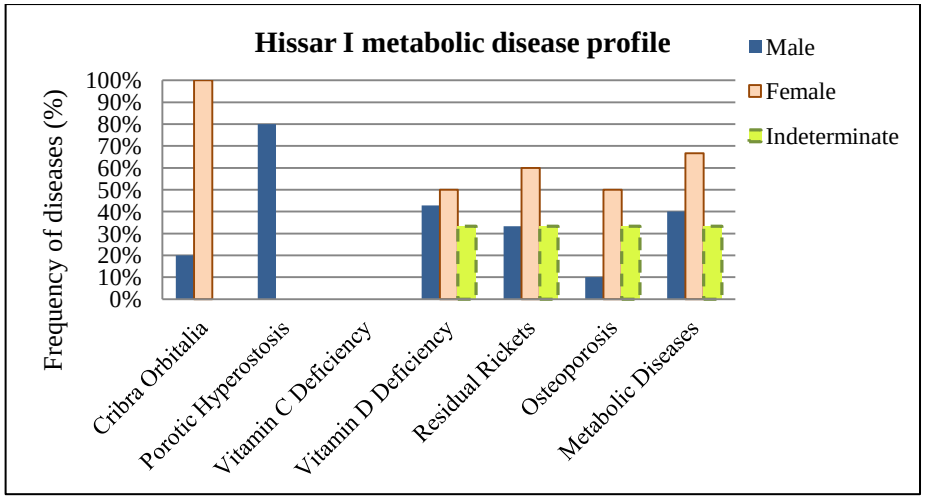


Fig 7.55. Hissar I: Metabolic disease profile by sex

Nine of the 19 individuals preserved for observation were younger than 35 years old (10 individuals belonged to the unaged category (AA)) (Table7.35, Figure7.56). The YA2 showed a higher prevalence of metabolic disorders compared to YA1 (insignificant). One of two YA1 observed for CO was affected (50%), and one of four YA2 had this lesion (25%) (insignificant). In contrast, the prevalence of PH was 25% higher in YA2 in comparison to YA1 (insignificant).

Table 7.35. Hissar I: Metabolic disease profile by age-category

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	***X2***	***P***
Cribra Orbitalia	1/2	50%	1/4	25%	-	-	-	-	-	-	0.375	1.000
Porotic Hyperostosis	1/2	50%	3/4	75%	-	-	-	-	-	-	0.375	1.000
Vitamin C Deficiency	0/5	0%	0/4	0%	-	-	-	-	0/10	0%	-	-
Total Vitamin D Deficiency	1/3	33%	1/2	50%	-	-	-	-	5/10	50%	0.268	0.875
Residual Rickets/ Osteomalacia	1/3	33%	0/1	0%	-	-	-	-	5/10	50%	1.069	0.586
Osteopenia/Osteoporosis	1/5	20%	0/4	0%	-	-	-	-	4/10	40%	2.497	0.287
Total Metabolic Diseases	2/5	40%	2/4	50%	-	-	-	-	5/10	50%	0.148	0.929

P≤0.05

One of three YA1 (33%) and one of two YA2 (50%) showed pathological lesions of vitamin D deficiency (insignificant). The bone changes indicative of residual ricket/osteomalacia were seen in 33% of YA1 but no evidence was seen in adults older than 26 years. Almost 50% of unaged adults (AA) had evidence of residual rickets/or osteomalacia (insignificant). One of the five YA1 had osteopenia/osteoporosis (20%), and none of the YA2 were affected. The unaged adults (AA) showed a 40% (4/10) prevalence of osteopenia/osteoporosis (insignificant).

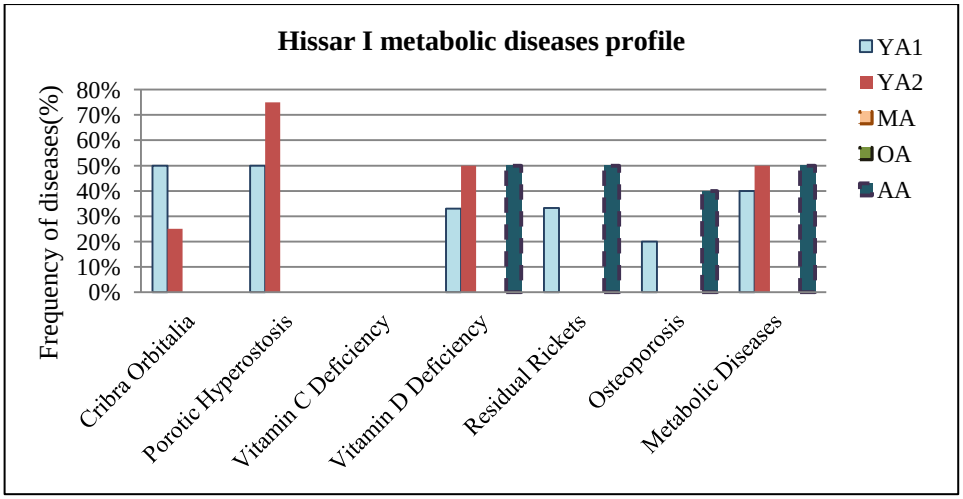


Fig 7.56. Hissar I: Metabolic disease profile by age-category

(ii)Dental pathology profile

Table 7.36 and Figure 7.57 summarise the dental pathology profiles for Hissar I for the males and females by individuals affected. Of the 28 individuals there was a total of 18 with teeth preserved for dental disease analysis, nine were male, eight were female and one was of unknown-sex.

Table 7.36. Hissar I: Dental pathology profiles by sex (individuals observed and affected)

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*p*
AMTL	2/9	22%	3/8	38%	0/1	0%	5/18	28%	0.900	0.638
Periapical lesions	2/9	22%	1/8	12%	0/1	0%	3/18	17%	0.500	0.779
Periodontal disease	0/9	0%	0/8	0%	0/1	0%	0/18	0%	-	-
Calculus	2/9	22%	2/8	25%	1/1	100%	5/18	28%	5.082	0.279
Caries	7/9	78%	2/8	25%	0/1	0%	9/18	50%	5.778	0.056
DEH	6/9	67%	6/8	75%	1/1	100%	13/18	72%	0.554	0.758
Attrition[a]	2/9	22%	1/8	12%	1/1	100%	4/18	22%	3.938	0.140

P≤0.05, [a]advanced (grades 7 and 8).

A total number of 306 teeth and 417 alveoli were available for study of true prevalence rates (TPR) for dental pathology based on tooth count (Table 7.37, Figure7.58). The frequency of AMTL, calculus (CAL), and DEH was higher among females than males. These differences were not statistically significant.

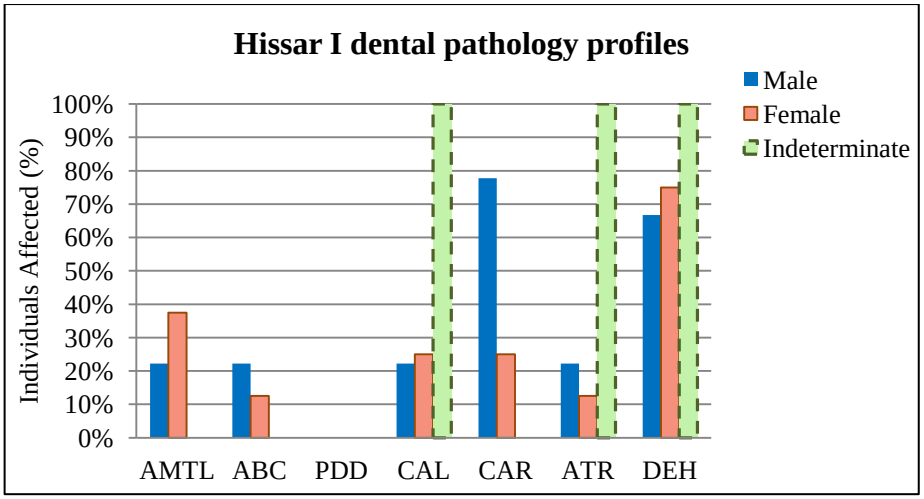


Fig 7.57. Hissar I: Dental pathology profiles by sex (individuals affected)

In contrast, males had higher rates of periapical lesions (ABC), caries (CAR) and attrition (ATR) than females (insignificant, except for caries). None of the individuals from Hissar I showed evidence of periodontal disease (0%).

Table 7.37. Hissar I: Dental pathology profiles by sex (teeth/tooth sockets affected)

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*P*
AMTL	3/240	1%	7/145	4.8%	0/32	0%	10/417	2%	0.993	0.609
Periapical lesions	2/240	1%	2/145	1%	0/32	0%	5/417	1%	0.401	0.818
Caries	15/163	9%	2/114	1.8%	0/29	0%	17/306	5.5%	6.166	**0.046**
DEH	41/53	77%	32/44	72.7%	9/9	100%	82/106	77%	1.415	0.493
Attrition[a]	7/163	4%	3/114	0.9%	11/29	38%	21/306	6.9%	5.252	0.072

P≤0.05, [a]advanced (grades 7 and 8).

The number of teeth affected by DEH was higher in males than females (insignificant).

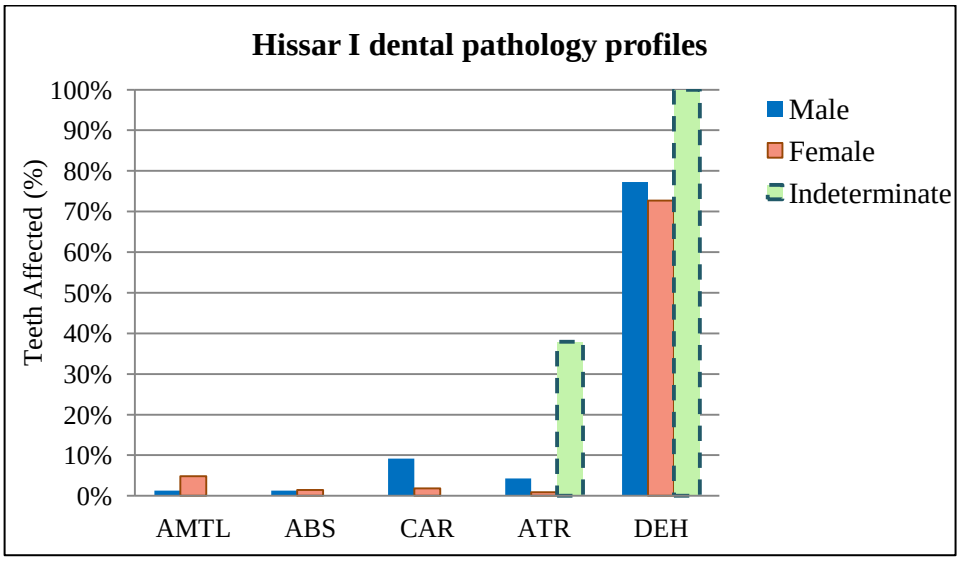


Fig 7.58. Hissar I: Dental pathology profiles by sex (teeth/tooth sockets affected)

Table 7.38 and Figure 7.59 illustrate the oral-health profile of Hissar I individuals by age-category based on TPR. Dental disease increased with age (insignificant, except attrition).

Table 7.38. Hissar I: Dental pathology profiles, by age-category (individuals observed and affected)

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*p*
AMTL	1/7	14%	2/8	25%	1/2	50%	-	-	1/1	100%	3.758	0.289
Periapical lesions	0/7	0%	2/8	25%	0/2	0%	-	-	1/1	100%	7.200	0.066
Periodontal disease	0/7	0%	0/8	0%	0/2	0%	-	-	0/1	0%	-	-
Calculus	2/7	29%	2/8	25%	1/2	50%	-	-	0/1	0%	2.967	0.813
Caries	3/7	43%	5/8	63%	0/2	0%	-	-	1/1	100%	3.643	0.303
DEH	4/7	57%	6/8	75%	2/2	100%	-	-	1/1	100%	1.978	0.577
Attrition[a]	0/7	0%	2/8	25%	2/2	100%	-	-	0/1	0%	9.321	**0.025**

P≤0.05, [a]advanced (grades 7 and 8).

Dental attrition was recorded among YA2, but it was more prevalent among MA; none of YA1 showed attrition (significant by tooth count and by individuals affected).

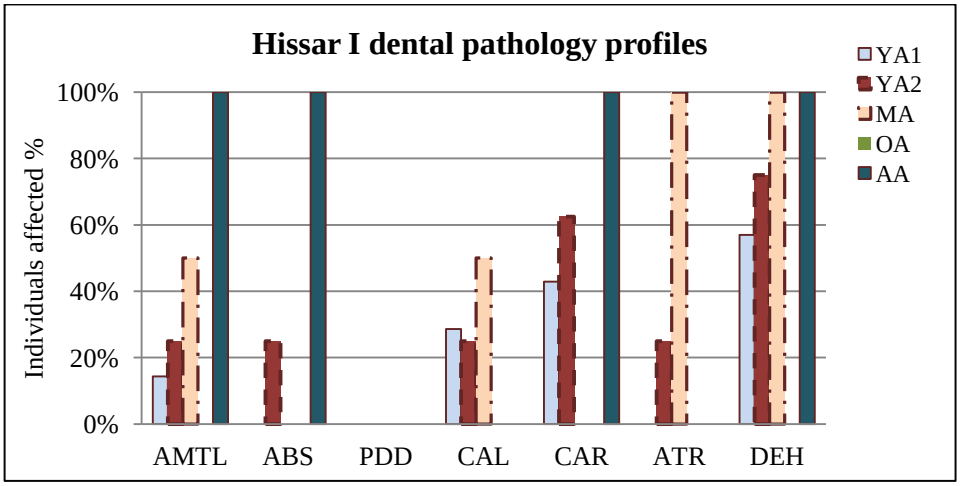


Fig 7.59. Hissar I: Dental pathology profiles by age (individuals affected)

Caries were more prevalent among adults younger than 35 years old (insignificant). However, based on the numbers of teeth affected (Table7.39 and Figure7.60), YA1 showed more lesions than the other age-groups (insignificant); but one must note the small sample size. The rate of DEH was lower among YA1 than the other age-groups (insignificant).

Table 7.39. Hissar I: Dental pathology profiles by age-category (teeth/tooth sockets affected)

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*P*
AMTL	1/144	1%	3/208	1%	4/48	8%	-	-	2/17	12%	4.647	0.200
Periapical lesions	0/144	0%	3/208	1%	0/48	0%	-	-	2/17	12%	7.336	0.062
Caries	9/114	8%	7/145	5%	0/40	0%	-	-	1/7	14%	2.256	0.521
DEH	21/41	51%	42/46	91%	15/15	100%	-	-	4/4	100%	2.691	0.442
Attrition[a]	0/114	0%	7/145	5%	14/40	35%	-	-	0/7	0%	9.567	**0.023**

P≤0.05, [a]advanced (grades 7 and 8).

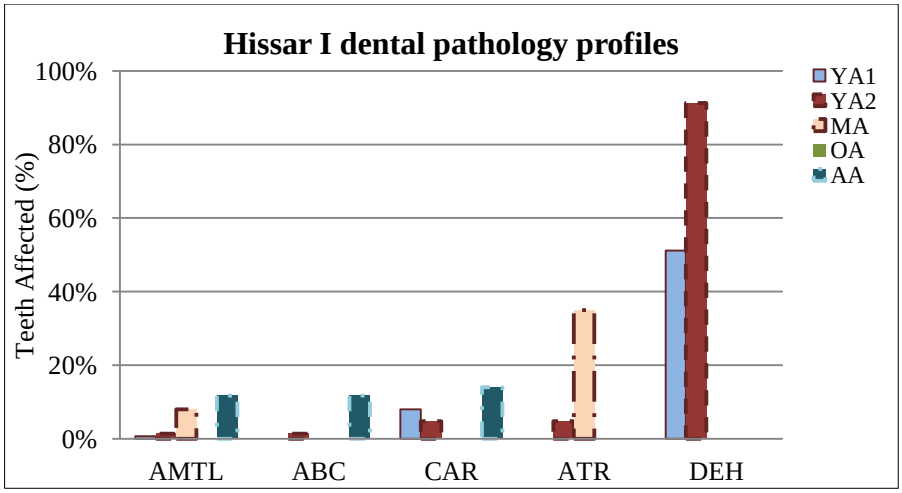


Fig 7.60. Hissar I: Dental pathology profiles by age (teeth/tooth sockets affected)

7.5.2. Hissar II

(i) Metabolic disease profile

Table 7.40 and Figure 7.61 exhibit the metabolic disease profile for Hissar II by sex. There were 53 individuals available for study in this period, and 43 were preserved well enough to record metabolic diseases. Thirty individuals showed pathological bone changes consistent with metabolic disorders (70%). The prevalence of metabolic diseases overall was 2% higher among the males compared to females (insignificant). There were seven males preserved to observe CO and they all had the lesion (100%). Among females 64% (7/11) had evidence (insignificant). The frequency of PH was 4% higher among males than females (insignificant).

Table 7.40. Hissar II: Metabolic disease profile by sex

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	***X2***	***P***
Cribra Orbitalia	7/7	100%	7/11	64%	-	-	14/18	78%	3.273	0.119
Porotic Hyperostosis	6/7	86%	9/11	82%	-	-	15/18	83%	0.470	1.000
Vitamin C Deficiency	0/15	0%	0/25	0%	0/3	0%	0/43	0%	-	-
Total Vitamin D Deficiency	9/13	69%	12/20	60%	1/3	33%	22/36	61%	1.345	0.510
Residual Rickets/Osteomalacia	6/11	54%	9/18	50%	1/3	33%	16/32	50%	0.424	0.809
Osteopenia/Osteoporosis	6/15	40%	7/25	28%	1/3	33%	14/43	33%	0.616	0.735
Total Metabolic Diseases	11/15	74%	18/25	72%	1/3	33%	30/43	70%	2.038	0.361

P≤0.05

Among 43 individuals observed for lesions indicative of vitamin C deficiency, none of them showed evidence. Almost 61% of individuals showed bone changes indicative of vitamin D deficiency, with the highest prevalence found in males (69%) compared to females (60%) (insignificant). Males demonstrated a higher rate of residual rickets/osteomalacia (54%) compared to the females (50%) (insignificant). The % of those affected with osteopenia/osteoporosis was 12% less among females when compared to males (insignificant).

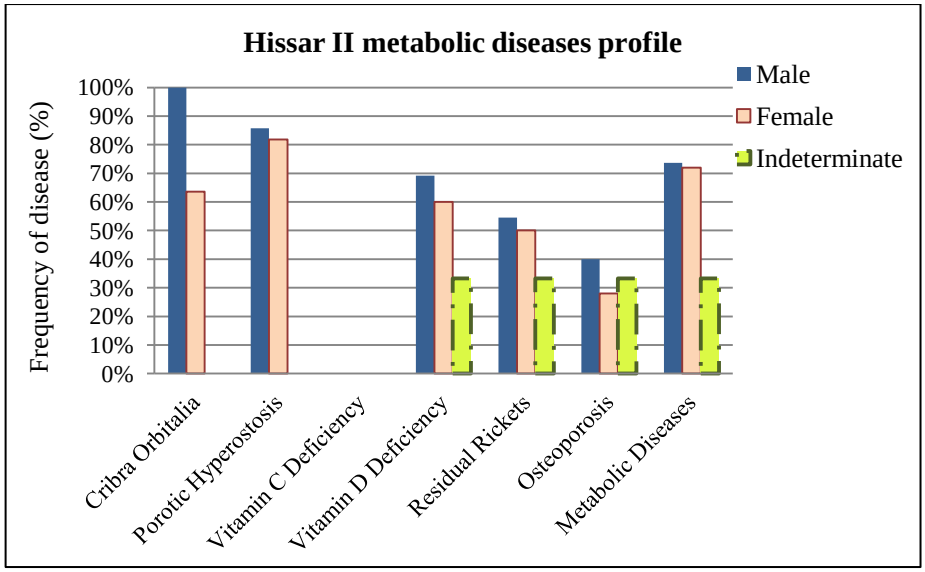


Fig 7.61. Hissar II: Metabolic disease profile by sex

Table 7.41 and Figure 7.62 summarise the prevalence of metabolic diseases in 43 adults by age-category. The prevalence of metabolic disease in this period increased with age, and the OA group showed the highest (100%) rate. However, the prevalence rate was considerably higher (71%) among YA1 and YA2 (insignificant). The highest frequency of CO was recorded in MA and OA (100%), while YA1 had the lowest rate (50%) (insignificant). In contrast, the prevalence of PH was higher among YA1 and YA2 (100%) than MA (60%) and OA (67%) (insignificant).

Table 7.41. Hissar II: Metabolic disease profile by age-category

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	***X2***	***P***
Cribra Orbitalia	2/4	50%	4/6	67%	5/5	100%	3/3	100%	-	-	4.5	0.212
Porotic Hyperostosis	4/4	100%	6/6	100%	3/5	60%	2/3	67%	-	-	4.56	0.207
Vitamin C Deficiency	0/7	0%	0/7	0%	0/8	0%	0/3	0%	0/18	0%	-	-
Total Vitamin D Deficiency	2/5	40%	3/4	75%	5/7	71%	2/2	100%	10/18	56%	3.082	0.544
Residual Rickets/Osteomalacia	2/5	40%	2/3	67%	4/6	67%	-	-	8/18	44%	1.422	0.700
Osteopenia/Osteoporosis	0/7	0%	1/7	14%	4/8	50%	1/3	33%	8/18	44%	6.711	0.152
Total Metabolic Diseases	5/7	71%	5/7	71%	7/8	87%	3/3	100%	10/18	56%	4.235	0.375

P≤0.05

The lowest prevalence rate of vitamin D deficiency was seen among YA1 (40%), but this rate increased to 75% in YA2; OA showed the highest rate (100%) (insignificant). The prevalence rate for people with residual rickets/osteomalacia was 27% lower among YA1 compared to YA2 (67%) (insignificant). YA1 had no evidence of osteopenia/osteoporosis ((0/7) 0%), but the rate increased gradually to 14% and 50% among YA2 and MA, respectively; almost 33% of OA were affected (insignificant).

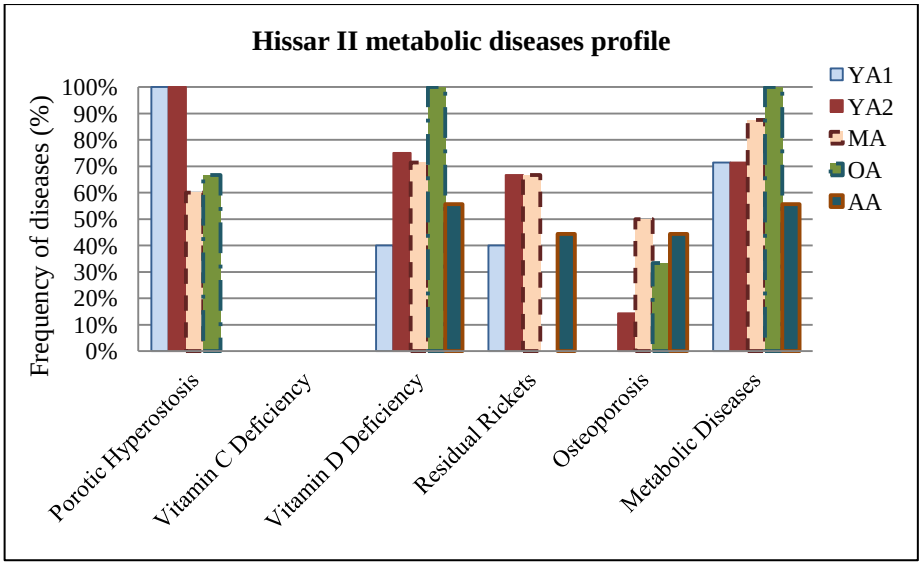


Fig 7.62. Hissar II: Metabolic disease profile by age-category

(ii) *Dental pathology profile*

Table 7.42 and Figure 7.63 summarises the dental pathology profiles for Hissar II individuals by sex and individuals affected. A total of 27 adults with preserved teeth were available for dental disease analysis, of which 10 were male, 16 female and one was of unknown-sex.

Table 7.42. Hissar II: Dental pathology profiles by sex (individuals observed and affected)

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*p*
AMTL	6/10	60%	12/16	75%	0/1	0%	18/27	67%	2.700	0.259
Periapical lesions	7/10	70%	10/16	63%	0/1	0%	17/27	63%	1.914	0.384
Periodontal disease	4/10	40%	4/16	25%	0/1	0%	8/27	67%	1.101	0.577
Calculus	6/10	60%	7/14	50%	0/1	0%	13/25	52%	2.708	0.608
Caries	3/10	30%	3/14	21%	0/1	0%	6/25	24%	0.564	0.754
DEH	4/7	57%	10/12	83%	0/1	0%	14/20	70%	3.900	0.142
Attrition[a]	8/10	80%	3/13	23%	0/1	0%	11/24	46%	8.260	**0.016**

P≤0.05, [a]advanced (grades 7 and 8).

A total of 407 teeth/723 alveoli were preserved for TPR study of dental pathology (Table 7.43, Figure 7.64). The males showed a higher % of periodontal disease (15%), periapical lesions (7%), calculus (10%), caries (9%) and attrition (80%) than females (insignificant, except attrition).

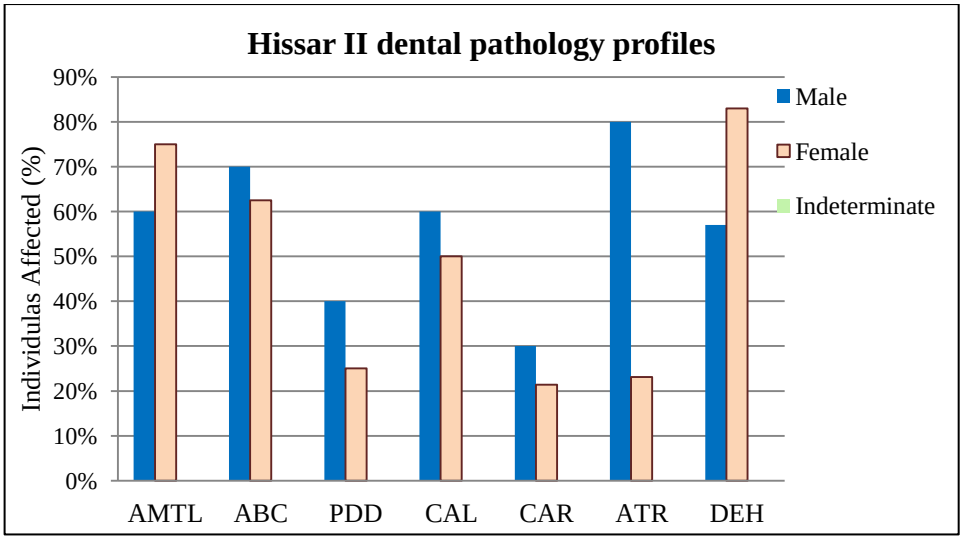


Fig 7.63. Hissar II: Dental pathology profiles by sex (individuals affected)

In contrast, the females had higher rates of AMTL and DEH than males (both insignificant).

Table 7.43. Hissar II: Dental pathology profiles by sex (teeth/tooth sockets affected)

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*P*
AMTL	28/289	9.7%	74/418	17.7%	0/16	0%	102/723	14%	1.733	0.420
Periapical lesions	25/289	8.6%	35/418	8.4%	0/16	0%	60/723	8.3%	1.478	0.478
Caries	4/167	2.4%	5/225	2.2%	0/15	0%	9/407	2.0%	0.498	0.780
DEH	30/43	70%	50/57	88%	0/6	0%	80/106	75.5%	1.738	0.419
Attrition[a]	63/167	38%	17/225	7.5%	0/15	0%	80/407	19.6%	10.471	**0.005**

P≤0.05, [a]advanced (grades 7 and 8).

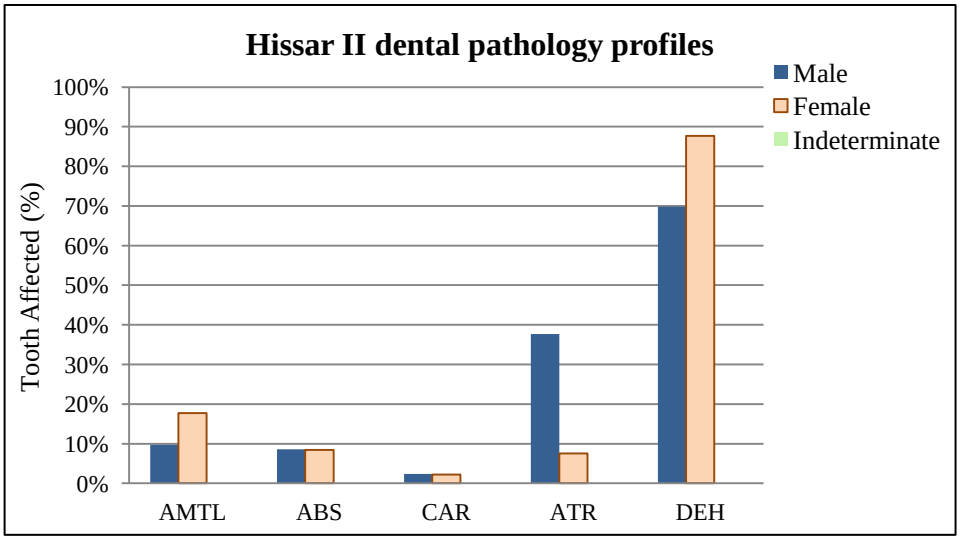


Fig 7.64. Hissar II: Dental pathology profiles by sex (teeth/tooth sockets affected)

Table 7.44 and Figure 7.65 show the dental pathology profile for the different age-groups by individuals affected. The dental pathology rate was higher among OA (50+) and MA individuals. However, the percentage of AMTL (57%) and periapical lesions were considerably higher (57%) among YA1. The AMTL rate was higher among MA (75%) (insignificant) (Table 7.45, Figure 7.66).

Table 7.44. Hissar II: Dental pathology profiles, by age (individuals observed and affected)

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*P*
AMTL	4/7	57%	4/8	50%	6/8	75%	3/3	100%	1/1	100%	3.536	0.472
Periapical lesions	4/7	57%	3/8	38%	7/8	87%	3/3	100%	0/1	0%	7.856	0.097
Periodontal disease	0/7	0%	0/8	0%	5/8	63%	2/3	67%	1/1	100%	14.81	**0.005**
Calculus	3/7	43%	5/8	73%	3/7	43%	2/2	100%	0/1	0%	5.766	0.673
Caries	2/7	29%	0/8	0%	3/7	43%	1/2	50%	0/1	0%	5.028	0.284
DEH	5/6	83%	5/5	100%	3/6	50%	1/1	100%	0/1	0%	6.508	0.164
Attrition[a]	0/6	0%	4/8	50%	5/7	71%	2/2	100%	0/1	0%	10.190	**0.037**

P≤0.05, [a]advanced (grades 7 and 8).

The highest % rate of periodontal disease was recorded from individuals older than 36 years when compared with no evidence from younger individuals (X^2=14.81, *p*=0.005). Dental caries was more frequent among adults over 36 years old (MA and OA) (insignificant).

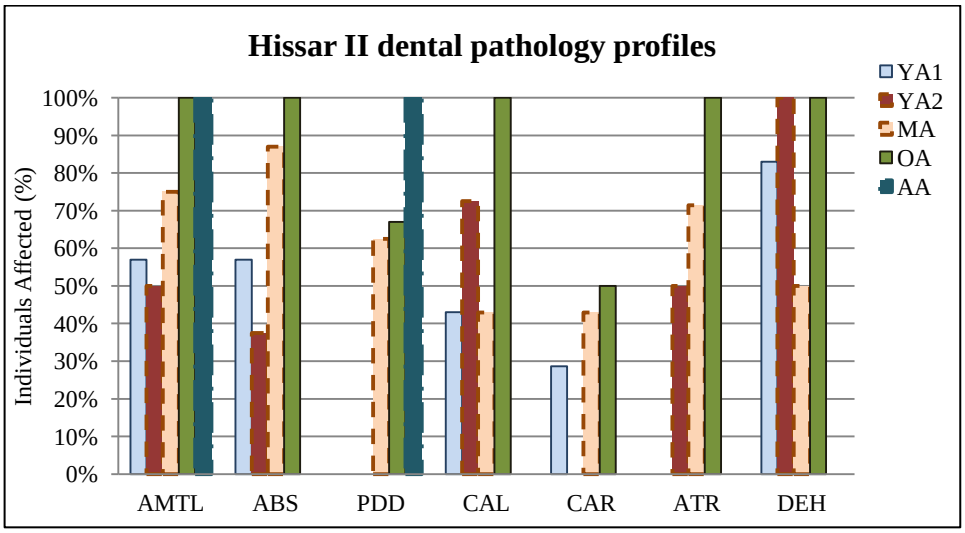


Fig 7.65. Hissar II: Dental pathology profiles, by age (individuals affected)

Dental attrition was recorded in adults older than 26 years, but was more pronounced in OA (significant).

Table 7.45. Hissar II: Dental pathology profiles, by age (teeth/tooth sockets affected)

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*P*
AMTL	17/193	8.8%	16/203	8%	30/233	13%	32/85	38%	7/9	78%	6.593	0.159
Periapical lesions	9/193	4.6%	14/203	7%	28/233	12%	9/85	11%	0/9	0%	5.844	0.211
Caries	2/126	1.6%	0/135	0%	4/116	3%	3/27	11%	0/3	0%	5.252	0.262
DEH	27/33	82%	39/39	100%	12/26	46%	2/7	28.6%	-	-	7.848	0.097
Attrition[a]	0/126	0%	19/135	14%	45/116	39%	16/27	59%	0/3	0%	10.104	**0.039**

P≤0.05, [a]advanced (grades 7 and 8).

The rate of DEH both in individuals and teeth affected was slightly higher among YA2 than YA1 (insignificant).

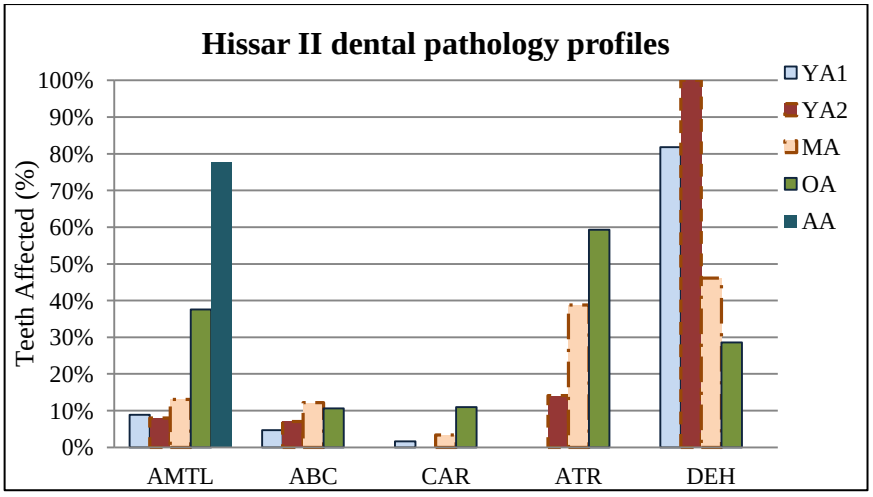


Fig 7.66. Hissar II: Dental pathology profiles, by age (teeth/tooth sockets affected)

7.5.3. Hissar III

(i) Metabolic disease profile

Table 7.46 and Figure 7.67 demonstrate the metabolic disease profile from Hissar III by comparing the prevalence of disease between the sexes. Of 287 individuals available for study, 251 were preserved well enough to observe bone changes of metabolic diseases; 185 of those showed pathological bone changes consistent with these diseases (74%). The females of this period showed the highest prevalence rate (77%) when compared to the males (71%) (insignificant). There were 120 individuals with at least one observable orbit, and 66 of those individuals showed CO. The females displayed a higher prevalence of CO (63%) compared to males (49%) (insignificant). In contrast, the prevalence of PH was 8% higher in males (insignificant). The prevalence rate of vitamin C deficiency was the lowest for all the metabolic diseases (0.8%). However, one female (1%) and one male (0.8%) had pathological bone changes indicative of possible vitamin C deficiency (insignificant).

Table 7.46. Hissar III: Metabolic disease profile by sex

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*P*
Cribra Orbitalia	35/71	49%	31/49	63%	-	-	66/120	55%	2.286	0.141
Porotic Hyperostosis	65/71	92%	41/49	84%	-	-	106/120	88%	1.745	0.249
Vitamin C Deficiency	1/126	1%	1/113	1%	0/12	0%	2/251	1%	0.108	0.948
Total Vitamin D Deficiency	72/106	68%	67/99	68%	8/12	67%	147/217	67%	0.008	0.996
residual Rickets/ Osteomalacia	39/86	45%	29/88	33%	5/12	42%	73/186	39%	2.834	0.242
Osteopenia/Osteoporosis	49/126	39%	54/113	48%	4/12	33%	107/251	43%	2.374	0.305
Total Metabolic Diseases	90/126	71%	87/113	77%	8/12	67%	185/251	74%	1.273	0.529

P≤0.05

A total of 67% of individuals were affected by vitamin D deficiency; the rate was identical in males and females (68%) but at 67% for unsexed individuals (insignificant). The prevalence of residual rickets/osteomalacia was 12% higher in males compared to

females (insignificant). The females suffered more osteopenia/osteoporosis (48%) than males (39%) (insignificant).

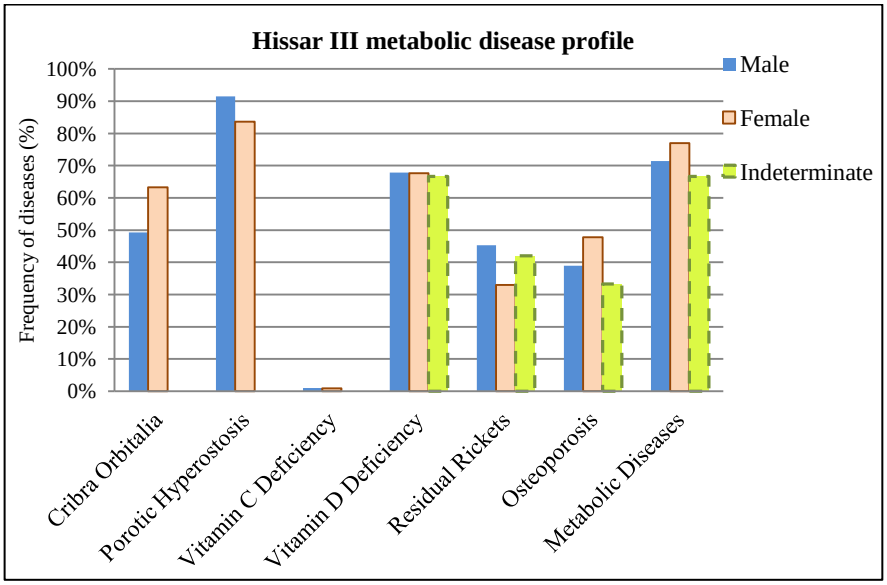


Fig 7.67. Hissar III: Metabolic disease profile by sex

The prevalence of metabolic diseases between the age-categories is summarised in Table 7.47 and Figure 7.68. It illustrates that the frequency of metabolic diseases increased with increasing age, and that YA1 had the lowest rate (61%) seen in the other age-categories. The prevalence increased gradually in YA2 (72%), MA (94%), and OA (100%). The differences in prevalence noted for metabolic diseases between the different age-categories were significant. The lowest prevalence rate for CO was seen in YA1 (45%). The YA2 had a higher prevalence (62%) which decreased to 53% among MA. The highest rate was seen in the OA (67%) (insignificant). The prevalence of PH was identical in YA1 and MA (90%), but it was 83% for YA2 (insignificant). There were two individuals in the third age-category (MA) showing possible bone changes of vitamin C deficiency (3%), but there was no evidence in the other four age-groups.

Table 7.47. Hissar III: Metabolic disease profile by age-category

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	***X2***	***P***
Cribra Orbitalia	9/20	45%	26/42	62%	27/51	53%	4/6	67%	0/1	0%	3.257	0.516
Porotic Hyperostosis	18/20	90%	35/42	83%	46/51	90%	6/6	100%	1/1	100%	2.169	0.705
Vitamin C Deficiency	0/33	0%	0/60	0%	2/67	3%	0/7	0%	0/84	0%	5.537	0.237
Total Vitamin D Deficiency	12/25	48%	30/48	62%	48/55	87%	6/6	100%	51/83	61%	19.03	**0.001**
Residual Rickets/Osteomalcia	5/20	25%	13/38	34%	21/42	50%	2/3	67%	32/83	39%	5.106	0.277
Osteopenia/Osteoporosis	8/33	24%	20/60	33%	40/67	60%	5/7	71%	34/84	41%	17.20	**0.002**
Total Metabolic Diseases	20/33	61%	43/60	72%	63/67	94%	7/7	100%	52/84	62%	25.86	**0.000**

P≤0.05

The highest prevalence rate for vitamin D deficiency was seen among OA (100%), but there was a decrease to 87% and 62% among MA and YA2, respectively.

The frequency of the vitamin D deficiency was 14% lower among YA1 than YA2 (significant). The frequency of residual rickets/osteomalcia increased with increasing age, with the lowest % rate recorded in YA1 (25%) and the highest in the OA (67%) (insignificant). The prevalence rate for osteopenia/osteoporosis increased with age in this period (significant). The YA1 showed a 24% prevalence when compared to 33%, 60%, and 71% in YA2, MA, and OA, respectively.

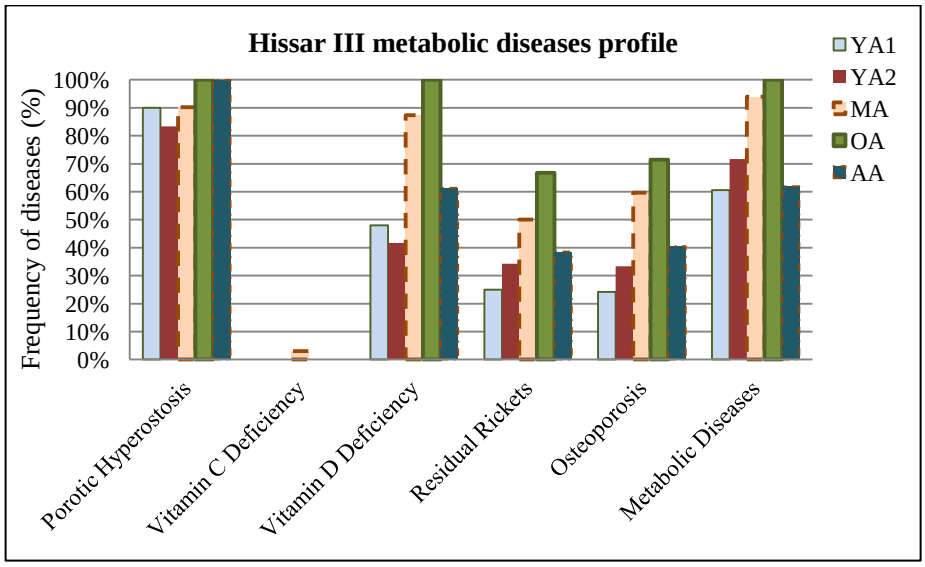


Fig 7.68. Hissar III: Metabolic disease profile by age-category

(ii)Dental pathology profile

Table 7.48 and Figure 7.69 compare the dental pathology profile of females and males from Hissar III. They show that almost all dental diseases were seen at a higher frequency rate in males. A total of 169 individuals with teeth preserved were used to assess dental disease (95 male, 68 female, and 6 unsexed "indeterminate" individuals).

Table 7.48. Hissar III: Dental pathology profiles by sex (individuals observed and affected)

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	***P***
AMTL	51/95	54%	29/68	43%	0/6	0%	80/169	47%	7.528	**0.023**
Periapical lesions	63/95	66%	38/68	56%	2/6	33%	102/169	60%	3.805	0.149
Periodontal disease	22/95	23%	8/68	12%	0/6	0%	30/169	18%	4.866	0.088
Calculus	47/92	51%	36/66	56%	6/6	100%	89/164	54%	6.588	0.361
Caries	34/92	37%	23/66	35%	1/6	17%	57/163	35%	1.027	0.598
DEH	54/71	76%	40/52	77%	3/5	60%	97/128	76%	0.718	0.698
Attrition[a]	52/92	56.5%	32/66	48.5%	3/6	50%	87/164	53%	1.020	0.601

P≤0.05, [a]advanced (grades 7 and 8).

A total number of 2280 teeth and 4312 alveoli were available to determine total teeth and alveoli affected by dental pathology (Table 7.49, Figure7.70).The prevalence

rate of AMTL, periapical lesions, periodontal disease, caries, and attrition was higher among males than females (insignificant, except for AMTL).

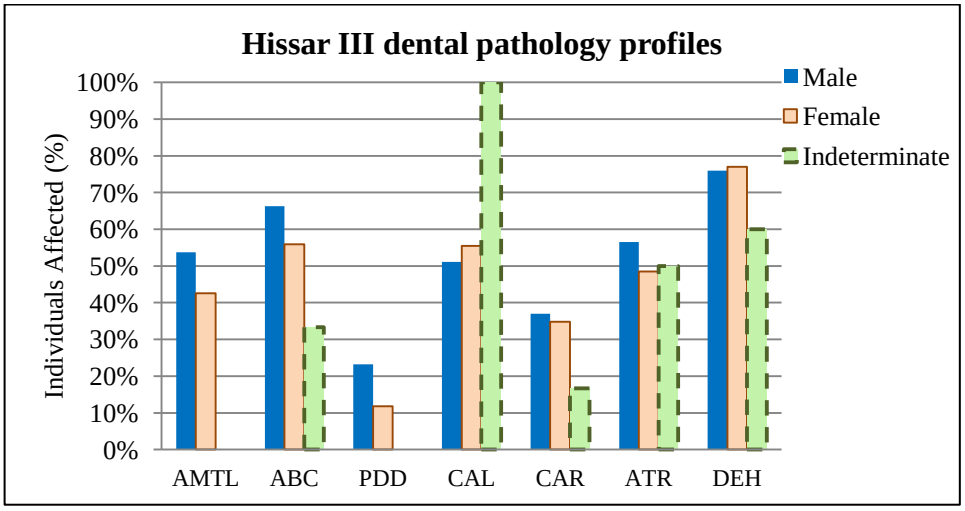


Fig 7.69. Hissar III: Dental pathology profiles by sex (individuals observed and affected)

In contrast, the females showed slightly higher levels of DEH (1%) and calculus (4%) than males (insignificant). The prevalence rate of DEH by tooth count in males (87%) was higher than in females (77%) (insignificant).

Table 7.49. Hissar III: Dental pathology profiles by sex (teeth/tooth sockets affected)

Disease	Male		Female		Indeterminate		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	X^2	*P*
AMTL	337/2466	14%	156/1734	10%	0/112	0%	493/4312	11%	6.66	**0.024**
Periapical lesions	214/2466	10%	119/1734	7%	3/112	3%	336/4312	8%	6.32	0.077
Caries	72/1216	6%	55/971	5.6%	1/93	1%	128/2280	6%	2.61	0.542
DEH	256/295	87%	205/265	77%	20/31	65%	481/591	81%	0.06	0.967
Attrition[a]	432/1216	36%	181/971	19%	19/93	20%	632/2280	28%	3.47	0.176

P≤0.05, [a]advanced (grades 7 and 8).

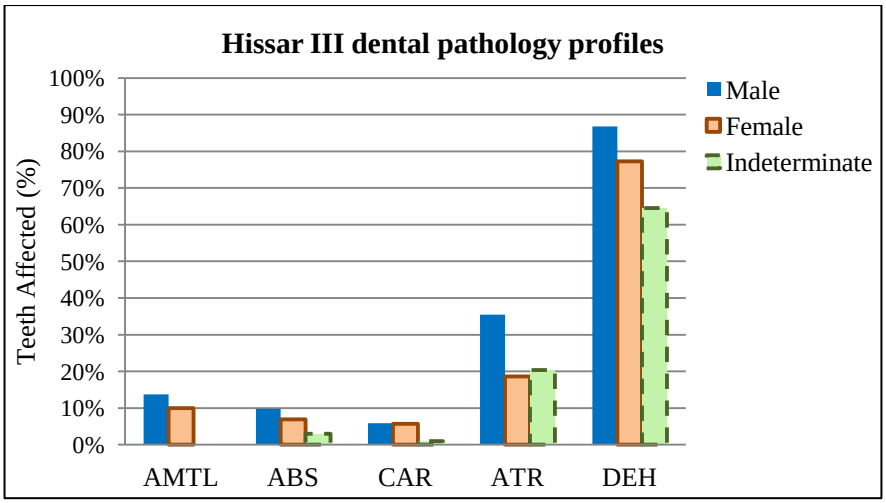


Fig 7.70. Hissar III: Dental pathology profiles by sex (teeth/tooth sockets affected)

Table 7.50 and Figure 7.71 illustrate the dental disease profile by age-category, showing that dental disease increased with increasing age. The individuals in the YA1 age-group had the lowest prevalence rate for AMTL (19%), while the highest rate was

reported for OA (83%) (individuals X^2 24.33, p=0.000), (teeth affected X^2=30.320, p=0.000) (Table 7.51, Figure7.72). Periapical lesions were more prevalent among individuals older than 36 years old (MA 80% and OA 83%), but YA1 also showed a 19% prevalence (X^2=36.31, p=0.000), and the alveoli affected showed a significant difference in all age-groups.

Table 7.50. Hissar III: Dental pathology profiles by age-category (individuals observed and affected)

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	***X²***	***P***
AMTL	5/27	19%	22/62	36%	46/71	65%	5/6	83%	2/3	67%	24.33	**0.000**
Periapical lesions	5/27	19%	33/62	52%	57/71	80%	5/6	83%	3/3	100%	36.31	**0.000**
Periodontal disease	0/27	0%	6/62	10%	19/71	27%	4/6	67%	1/3	33%	22.87	**0.000**
Calculus	14/27	52%	39/61	64%	32/67	48%	3/6	50%	1/3	33%	16.99	0.150
Caries	5/27	29%	26/61	43%	24/67	36%	2/6	33%	1.3	33%	4.78	0.311
DEH	17/22	77%	41/51	80%	35/48	73%	3/5	60%	1/1	100%	2.23	0.693
Attrition[a]	4/27	15%	25/50	42%	53/69	77%	4/5	80%	1/3	33%	36.53	**0.000**

P≤0.05, [a]advanced (grades 7 and 8).

Periodontal disease was seen with increasing age, and not seen (0/27individual) among adults younger than 25 years (YA1). However, it increased gradually to 10% in YA2 and to 27% and 67% in MA and OA, respectively (X^2= 22.87, p=0.000).

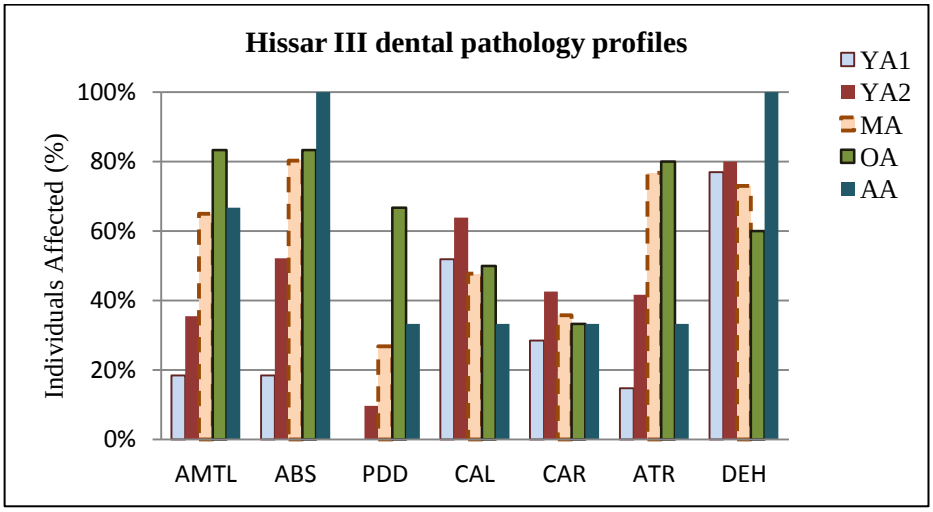


Fig 7.71. Hissar III: Dental pathology profiles by age-category (individuals observed and affected)

There was no significant difference in caries and calculus prevalence among individuals from different age-groups, although YA2 showed a higher rate of calculus (64%) and caries (43%) compared to the other age-groups in Hissar III. There was no significant difference in the prevalence rate of DEH among different age-groups.

Table 7.51. Hissar III: Dental pathology profiles by age-category (teeth/tooth sockets affected)

Disease	YA1		YA2		MA		OA		AA		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	*A/O*	*%*	***X²***	***P***
AMTL	18/647	3%	120/1598	8%	311/1846	17%	42/173	24%	2/48	4%	30.320	**0.000**
Periapical lesions	8/647	1%	89/1598	6%	205/1846	11%	28/173	16%	6/48	13%	41.588	**0.000**
Caries	19/382	5%	62/966	6%	43/842	6%	2/70	3%	1/20	5%	4.260	0.372
DEH	91/106	86%	217/267	81%	157/197	80%	14/16	88%	2/2	100%	4.677	0.322
Attrition[a]	22/382	3%	165/966	17%	376/842	45%	65/70	93%	4/20	20%	37.094	**0.000**

P≤0.05, [a]advanced (grades 7 and 8).

The rate of attrition in individuals was more marked among adults older than 36 years (MA:77% and OA:80%), but YA1 also demonstrated attrition (15%) which increased to 42% in the YA2 age-range (X^2=36.537,p=0.000),(teeth affected X^2=37.094, p=0.000).

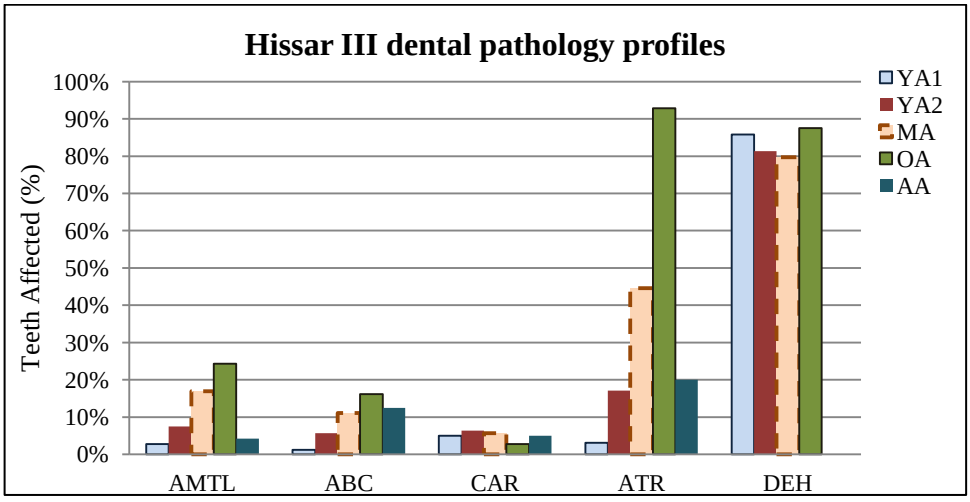


Fig 7.72. Hissar III: Dental pathology profiles by age-category (teeth/tooth sockets affected)

7.6. Comparative Analysis of the Chalcolithic and Bronze Age Populations

7.6.1. Preservation

Table 7.52 and Figure 7.73 provide a comparative analysis of the level of skeletal preservation of the *Tepe Hissar* skeletons by period. The level of preservation from the Hissar III period was better than other periods. It had the lowest % of skeletons in a poor state of preservation (42%) and the highest % of skeletons in good condition (9.4%). Almost 139 (48%) skeletons of this period were in a partial state of preservation. The level of preservation in Hissar II period was better than at Hissar I where almost 7.5% of the skeletons were in good condition, while 40% were in a partial state of preservation. Overall, the majority of human skeletal remains from *Tepe Hissar* were in a poor state of preservation (48%), while 44% of those were in better condition and more complete. Approximately 8.4% of were in a good state of preservation (X^2=64.085, p=0.000).

Table 7.52. Comparison of skeletal preservation of Tepe Hissar population, by periods

Preservation	**Good (>75%)**		**Partial (25-75%)**		**Poor (<25%)**	
Tepe Hissar Period	*NO.*	*%*	*NO.*	*%*	*NO.*	*%*
Hissar I	-	-	3	11%	25	89%
Hissar II	4	7.5%	21	40%	28	53%
Hissar III	27	9.4%	139	48%	121	42%
Total	31	8.4%	163	44%	174	47%

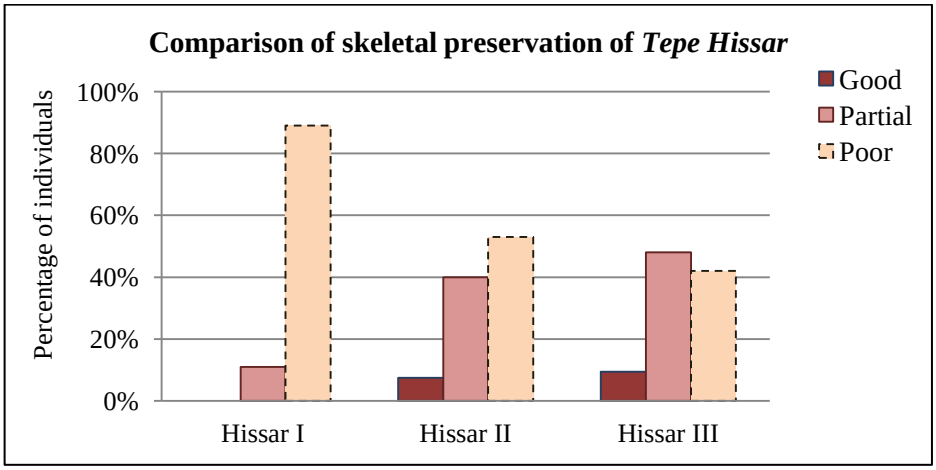


Fig 7.73. Comparison of skeletal preservation of the Tepe Hissar population

7.6.2. Palaeodemographic Profiles

(i) Sex

Table 7.53 and Figure 7.74 compare the sex distribution for the skeletons for the *Tepe Hissar*. A total of 368 adults were available for analysis. The distribution of males (46.7%) was slightly higher than females (45.6%). There were 28 unsexed or "indeterminate" individuals (7.6%). The % of females (58.5%) available for this study from Hissar II was more than males of this period (32.1%), but in Hissar III (49%) and Hissar I (50%) the % of males were more similar to females at 44% and 36%, respectively (insignificant).

Table 7.53. Comparison of sex distribution of Tepe Hissar population, by periods

	Hissar I		**Hissar II**		**Hissar III**		**Total**	
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
Male	14	50%	17	32.1%	141	49.1%	172	46.7%
Female	10	35.7%	31	58.5%	127	44.3%	168	45.6%
Indeterminate	4	14.3%	5	9.4%	19	6.6%	28	7.6%
Total	28	7.4%	53	14%	287	76.1%	368	100%

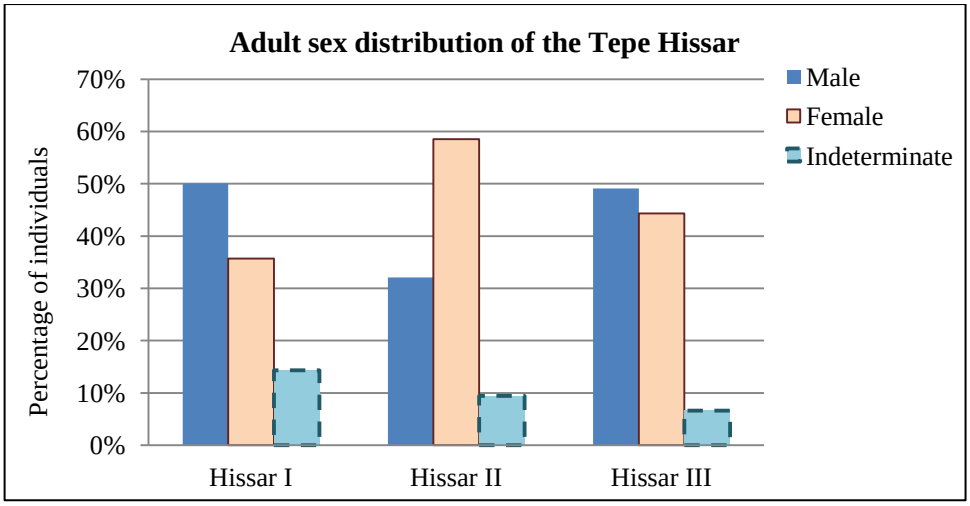


Fig 7.74. Comparison of the sex distribution of the Tepe Hissar population, by period

(ii) Mortality profile

(a) Female mortality profile

Table 7.54 and Figure 7.75 compare age-at-death group frequencies for females at *Tepe Hissar*. Overall, the highest mortality rate (26%) was recorded for YA2 (26 and 35 years old) and the second highest rate belonged to MA (20.8%).

Table 7.54. Mortality profile for the females at Tepe Hissar

		Hissar I		**Hissar II**		**Hissar III**		**Total**	
Age-category	*Age*	*NO*	*%*	*NO*	*%*	*NO*	*%*	*NO*	*%*
YA1	18-25	5	50%	10	32.2%	17	13.4%	32	19%
YA2	26-35	1	10%	4	12.9%	39	30.7%	44	26%
MA	36-50	1	10%	4	12.9%	30	23.6%	35	20.8%
OA	50+	0	0%	2	6.5%	1	0.8%	3	1.8%
AA	18+	3	30%	11	35.5%	40	31.5%	54	32%
Total	-	10	5.7%	31	17.8%	127	72.9%	168	100%

Age-at-death was lower for both Hissar I and II, and more young females died between 18 and 25 years old (YA1) in comparison to those from period III. The mortality rate decreased sharply among the YA2 and MA age-groups in Hissar I and II. However, in Hissar III females between ages 26 and 35 (YA2) were more at risk of death than younger females. The proportion of females over 50 years (OA) in the Hissar II period was greater than for Hissar III. The mortality rate was lower in Hissar I and II as age increased. However, in Hissar III there were fewer young adult females dying between ages 18 and 25 years and more in the older age-categories (significant).

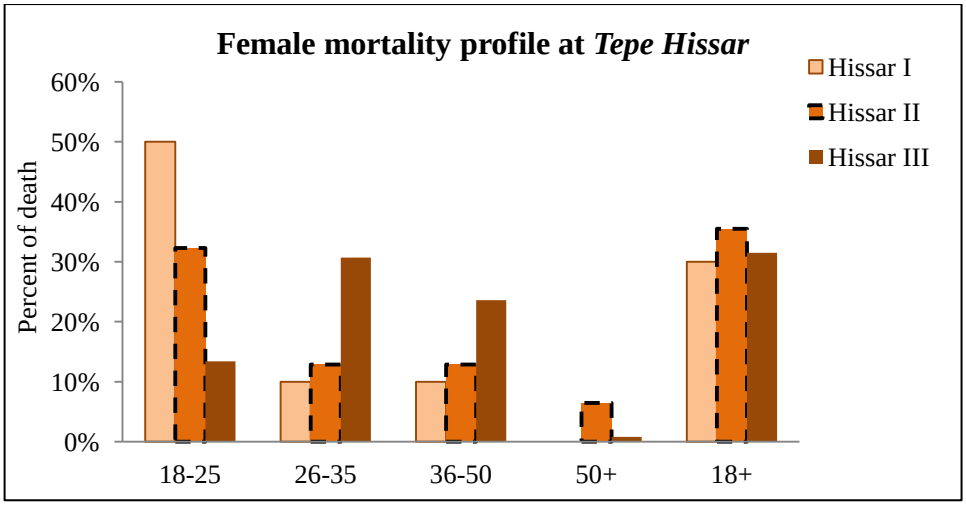


Fig 7.75. Mortality profile for females at Tepe Hissar, by period

(b) Male mortality profile

Table 7.55 and Figure 7.76 compare the mortality profile of males across the periods. Overall, the highest mortality rate was recorded for YA2 (31%), and the MA group (28%). Among the YA1 and YA2 categories, the proportion of male deaths at Hissar I (14%) was greater than for the other periods, the sample for the Hissar I and II periods is small. The mortality rate increased among Hissar III males with increasing age, and there were less young adults dying between 18 to 25 years old (YA1) in this period. However, this rate decreased when approaching the age class of over 50 years old (OA).

Table 7.55. Mortality profile for the males at Tepe Hissar

		Hissar I		**Hissar II**		**Hissar III**		**Total**	
Age-category	*Age*	*NO*	*%*	*NO*	*%*	*NO*	*%*	*NO*	*%*
YA1	18-25	2	14%	-	-	12	9%	14	8.1%
YA2	26-35	7	50%	5	29%	41	29%	53	30.8%
MA	36-50	0	0%	5	29%	44	31%	49	28.4%
OA	50+	0	0%	1	6%	6	4%	7	4%
AA	18+	5	36%	6	35%	38	27%	49	28.4%
Total	-	14	8%	17	9.8%	141	81%	172	100%

The percentage of male deaths was almost identical among the YA2 and MA age-categories for Hissar II and III (insignificant).

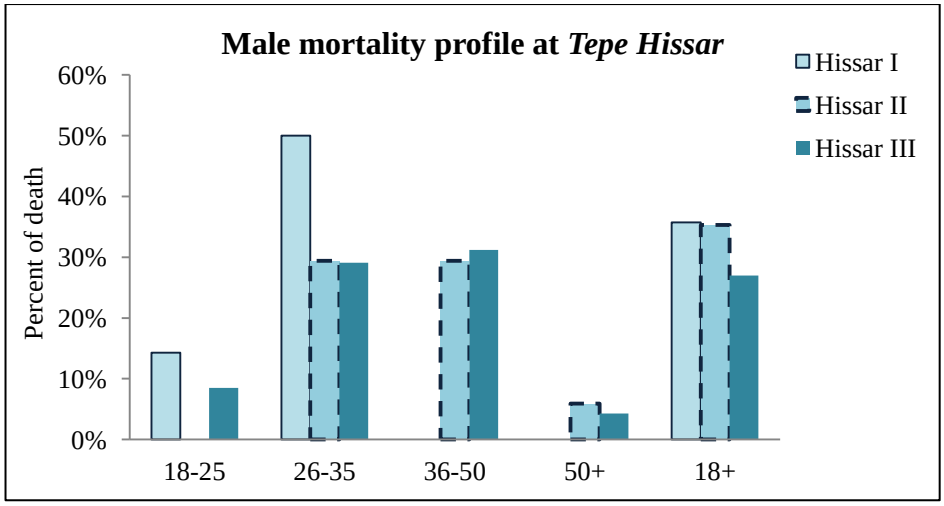


Fig 7.76. Mortality profile of males at Tepe Hissar, by period

(c) Mortality profile by pooled sex

Table 7.56 and Figure 7.77 illustrate mortality profiles for the different periods at *Tepe Hissar* with the sexes pooled. A comparison of mortality profiles showed that the mortality rate among YA1 decreased from 25% in Hissar I to 20.8% in Hissar II, and finally to 10.5% in the Hissar III period. The mortality rate in the Hissar II was higher in the YA1 age-category, but it decreased with increasing age. In contrast, in Hissar III, this rate was more pronounced among the YA2 age-group (29.3%), but declined among the MA (26.1%).

Table 7.56. Mortality profile for the population (sexes pooled) at Tepe Hissar

		Hissar I		**Hissar II**		**Hissar III**		**Total**	
Age-category	*Age*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
YA1	18-25	7	25%	11	21%	30	10.5%	48	13%
YA2	26-35	8	28.6%	9	17%	84	29.3%	101	27.4%
MA	36-50	2	7.1%	9	17%	75	26.1%	86	23.3%
OA	50+	0	0%	3	5.7%	7	2.4%	10	2.7%
AA	18+	11	39.3%	21	39.6%	91	31.7%	123	33.4%
Total	-	28	100%	53	100%	287	100%	368	100%

An increase in the mortality rate among individuals aged 26 to 50 (YA2 and MA) was more noticeable in males than females. The number of people surviving to over 50 years was 5.7% for Hissar II and 2.4% for Hissar III (significant).

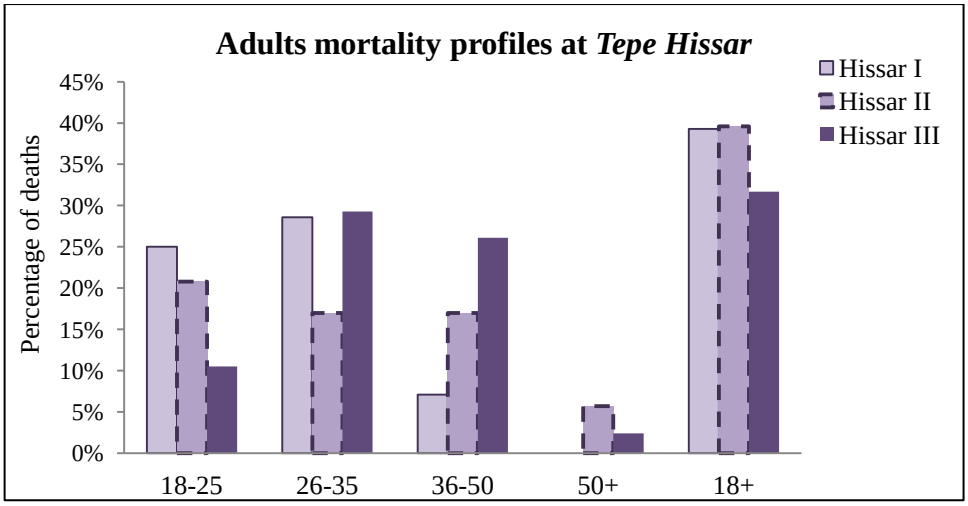


Fig 7.77. Mortality profiles of Tepe Hissar population by pooled sex

7.6.3. Stress and Disease Profiles

(i) Metabolic Disease Profiles

(a) Comparison of metabolic disease profiles for males at Tepe Hissar, by period

Comparative analysis of metabolic disease profiles for males from the three periods at *Tepe Hissar* is demonstrated in Table 7.57 and Figure 7.78. Of 151 males analysed, the evidence of pathological changes indicative of metabolic diseases was recorded in 105 individuals (69%). The prevalence rate overall for metabolic disease was 40% for Hissar I which increased to 74% for Hissar II, but in Hissar III the % decreased to 71% (insignificant). Of the 83 males who could be observed for evidence of CO and PH, 43 displayed evidence of CO and 75 showed PH. The majority of cranial vaults in this study showed light (scattered fine foramina) to medium (large and small isolated foramina linking into a trabecular structure) degree of expression. The prevalence rate of CO was lower among males from Hissar I (20%), but increased sharply to 100% in Hissar II, with a decrease to 49% in Hissar III (significant). In contrast, there was no significant difference in the proportion of people affected by PH in the three periods. The % of males affected was higher in Hissar III (95%) than in Hissar II (86%) and Hissar I (80%).

Table 7.57. Tepe Hissar male metabolic disease profiles by period

Disease	Hissar I		Hissar II		Hissar III		Total		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	A/O	%	***X2***	***P***
Cribra Orbitalia	1/5	20%	7/7	100%	35/71	49%	43/83	52%	8.717	**0.013**
Porotic Hyperostosis	4/5	80%	6/7	86%	65/71	92%	75/83	90%	0.905	0.636
Vitamin C Deficiency	0/10	0%	0/15	0%	1/126	1%	1/151	0.6%	0.208	0.976
Total Vitamin D Deficiency	3/7	43%	9/13	69%	72/106	68%	84/126	67%	2.405	0.493
Residual Rickets /Osteomalacia	2/6	33%	6/11	54%	39/86	45%	47/103	46%	1.555	0.670
Osteopenia/Osteporosis	1/10	10%	6/15	40%	49/126	39%	56/151	37%	5.037	0.169
Total Metabolic Diseases	4/10	40%	11/15	74%	90/126	71%	105/151	69%	4.887	0.180

P≤0.05

Of the 151 males analysed for evidence of vitamin C deficiency, one from Hissar III (1/126 (1%)) displayed evidence of possible vitamin C deficiency (insignificant). The males from Hissar I had the lowest level vitamin D deficiency, but in Hissar II the % affected increased to 69% and then decreased slightly to 68% in Hissar III (insignificant). The males of Hissar II showed the highest (54%) level of residual rickets/osteomalacia compared to Hissar I (33%) and Hissar III (45%) (insignificant). The rate of osteopenia/osteoporosis was 10% in Hissar I, which increased to 40% in Hissar II. The prevalence rate for Hissar III was almost identical to the Hissar II period (insignificant).

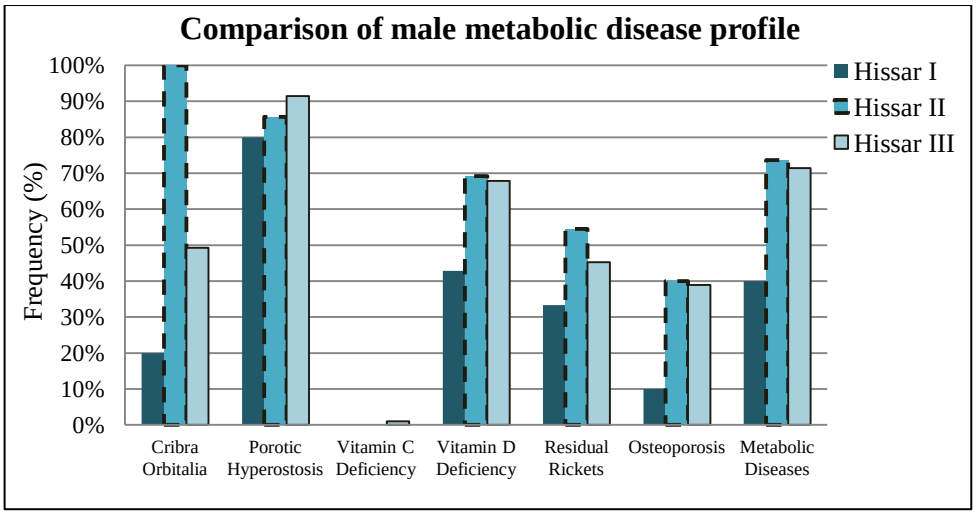


Fig 7.78. Male metabolic disease profiles at Tepe Hissar, by period

Overall metabolic disease increased over time among males at *Tepe Hissar*. The males from Hissar I period had the lowest rate compared to males from the other periods. However, the males from Hissar II displayed the highest prevalence of metabolic diseases (except for PH) compared to Hissar III and Hissar I (insignificant). Males from Hissar III had slightly lower levels of metabolic diseases compared to Hissar II, except for CO which was much lower in Hissar II. The rate of PH was slightly higher in Hissar III than in Hissar II.

(b) Comparison of metabolic disease profiles for females at Tepe Hissar, by period

Comparative analysis of metabolic disease profiles for females from the three periods at *Tepe Hissar* is demonstrated in Table 7.58 and Figure 7.79. Of 146 females analysed, evidence of pathological changes indicative of metabolic disease was recorded in 109 individuals (75%). The overall metabolic disease rate among females increased gradually from 67% in Hissar I to 72% in Hissar II, and to 77% in Hissar III (insignificant). Of a total of 61 females examined for CO and PH, 64% displayed evidence of CO and 82% showed evidence of PH. The prevalence rate of CO was slightly higher (1%) in Hissar II than Hissar III. There was only one female from Hissar I who had CO (100%) (insignificant). There was also no significant difference in the level of PH between females in the three periods. Of a total of 146 females observed for evidence of vitamin C deficiency, one from Hissar III (1%) showed possible evidence of this deficiency; none of the females from Hissar I and Hissar II showed any evidence (insignificant).

Table 7.58. Tepe Hissar females metabolic disease profiles by period

Disease	**Hissar I**		**Hissar II**		**Hissar III**		**Total**		**Comparison**	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	A/O	%	***X2***	***P***
Cribra Orbitalia	1/1	100%	7/11	64%	31/49	63%	39/61	64%	0.574	0.750
Porotic Hyperostosis	0/1	0%	9/11	82%	41/49	84%	50/61	82%	4.642	0.098
Vitamin C Deficiency	0/6	0%	0/25	0%	1/113	1%	1/146	1%	0.294	0.961
Total Vitamin D Deficiency	3/5	60%	12/20	60%	67/99	68%	82/124	66%	0.751	0.861
Residual Rickets /Osteomalacia	3/5	60%	9/18	50%	29/88	33%	41/111	37%	3.195	0.362
Osteopebia/Osteporosis	3/6	50%	7/25	28%	54/113	48%	64/144	44%	4.917	0.178
Total Metabolic Diseases	4/6	67%	18/25	72%	87/113	77%	109/146	75%	1.250	0.741

P≤0.05

The frequency of vitamin D deficiency was similar in both Hissar I and Hissar II (60%), but it increased a bit more in Hissar III (68%) (insignificant). Comparing the differences in the prevalence rate of residual rickets/osteomalacia and osteopenia/osteoporosis among females, statistical tests did not show significant differences. However, it showed that females from Hissar I had a higher level of residual rickets (60%) and osteoporosis (50%) when compared to females from the later periods. The level of osteopenia/osteoporosis was lowest in Hissar II (28%).

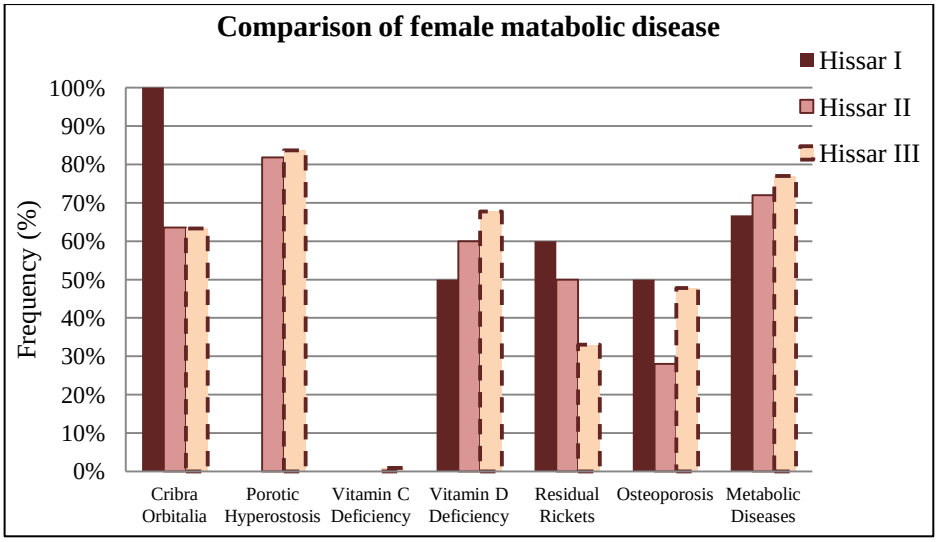


Fig 7.79. Female metabolic disease profiles at Tepe Hissar, by period

The overall rate of metabolic diseases increased over time among females at *Tepe Hissar*, except for CO, residual rickets/osteomalacia and osteopenia/osteoporosis. The females from Hissar I had the highest level of CO, residual rickets and osteoporosis when compared to females from Hisser II and III. The females from Hissar III displayed the highest rate of overall metabolic disease, vitamin D deficiency and PH; but they showed the lowest rate of residual rickets/osteomalacia and CO. The rates of overall metabolic diseases, CO, vitamin D deficiency and PH were slightly lower in females of Hissar II except for osteoporosis.

(c) Comparison of metabolic disease profiles of the Tepe Hissar population- Between periods

Table 7.59 and Figure 7.80 provide a summary of comparative analysis of the prevalence rate of metabolic diseases between the periods at *Tepe Hissar* pooled by sex and age (see Figures 7.81-82). Adult health declined over time, and overall metabolic disease increased. The prevalence rate of metabolic diseases was the lowest among individuals from Hissar I, but increased from 47% to 70% in Hissar II and to 74% in Hissar III (insignificant). The prevalence rate of CO increased to 78% in individuals from Hissar II compared to 33% in Hissar I, but declined to 23% in Hissar III (insignificant). Individuals from Hissar I had a lower level (67%) of PH than those from Hissar II (78%), but this rate was highest among Hissar III individuals (insignificant). Of the individuals analysed for evidence of vitamin C deficiency, except two individuals from Hissar III with evidence of possible vitamin C deficiency, none of the

individuals from Hissar I and Hissar II showed evidence of this deficiency (insignificant).

Table 7.59. Metabolic disease profile for Tepe Hissar population, by Period

Disease	Hissar I		Hissar II		Hissar III		Comparison	
	A/O	*%*	*A/O*	*%*	*A/O*	*%*	***X2***	***P***
Cribra Orbitalia	2/6	33%	14/18	78%	66/120	55%	4.736	0.094
Porotic Hyperostosis	4/6	67%	15/18	83%	106/120	88%	2.559	0.278
Vitamin C Deficiency	0/19	0%	0/43	0%	2/251	1%	0.529	0.912
Total Vitamin D Deficiency	7/15	48%	22/36	61%	147/217	67%	3.306	0.347
Residual Rickets /Osteomalacia	6/14	43%	16/32	50%	73/186	39%	1.460	0.692
Osteopebia/Osteporosis	5/19	26%	14/43	33%	107/251	43%	3.335	0.343
Total Metabolic Diseases	9/19	47%	30/43	70%	185/251	74%	6.128	0.106

P≤0.05

The overall level of vitamin D deficiency increased from 48% in Hissar I individuals to 61% in those from Hissar II, and this rate increased to 67% among individuals from Hissar III (insignificant).

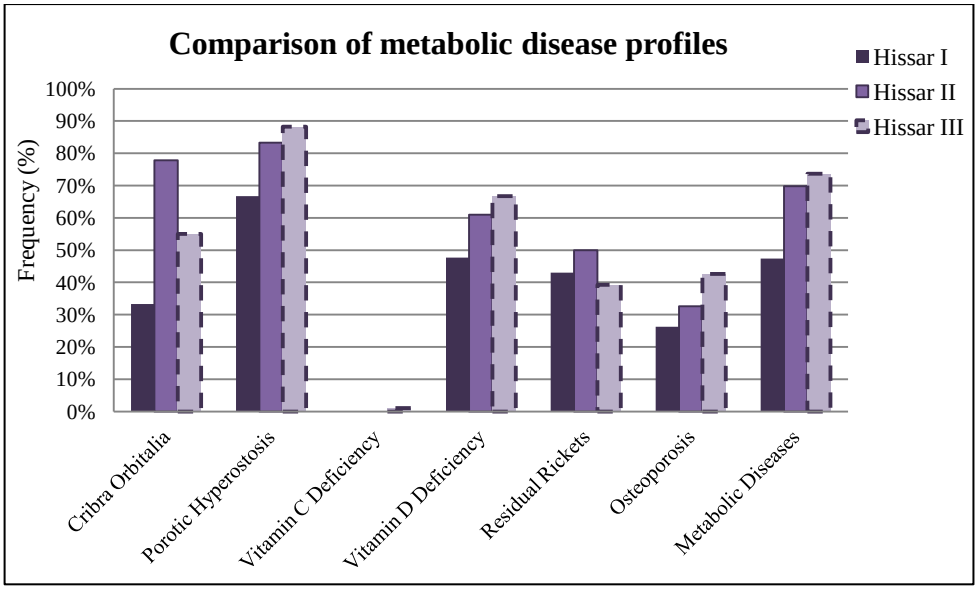


Fig 7.80. Metabolic disease profiles for the Tepe Hissar population, by period

Fig 7.81. Some samples of vitamin D deficiency from Tepe Hissar: (a) Deformation of right and left tibia, possible residual rickets/osteomalacia-Hissar III- Sk 33-23-158; (b) pseudofracture (Looser's zone) affecting the cortical bone surface of scapula- Hissar III-Sk 33-16-162; (c) Colles' fracture, Hissar I- Sk 33-16-5

Fig 7.82. Left: CO, Hissar II-Sk 33-23-24; right: PH, Hissar III- Sk 33-16-83

(ii) Dental Pathology Profiles

(a) Comparison of dental pathology profiles for males at Tepe Hissar, by period

A comparison of male dental diseases profiles, by period at *Tepe Hissar* is illustrated in Table 7.60 and Figure 7.83. The prevalence rate of AMTL was the lowest in Hissar I (22%), but it increased sharply to 38% higher in Hissar II (60%) and then decreased to 54% in Hissar III (insignificant). When considering the number of teeth/alveoli affected (Table 7.60, Figure 7.84), the data showed that the prevalence of AMTL was higher in males in Hissar III (14%) than in Hissar II (10%) and Hissar I

(1%). The average number of teeth lost per person was 3.5 (337/95), 2.8 (28/10), and 0.3 (3/9) for Hissar III, Hissar II and Hissar I, respectively (insignificant). There was a significant difference in the prevalence rate of periapical lesions among males from the different periods both in individuals and alveoli affected. The lowest rate of periapical lesions was recorded for males from Hissar I (individuals affected 22%, alveoli affected 1%) with an average of 0.3 teeth per person, and the highest seen in males of Hissar II period (70% of individuals affected), with an average of 2.5 alveoli per person affected, which later decreased to 66% in Hissar III (average 2.2 teeth per person). However, when counting the number of alveoli affected, the prevalence was higher for Hissar III (10%) than for Hissar II (9%).

Table 7.60. Comparison of dental pathology profiles for males at Tepe Hissar by period

Dental disease	Individuals affected		Teeth/tooth sockets affected	
	X^2	*P*	X^2	*P*
AMTL	4.618	0.202	5.327	0.149
Periapical lesions	8.736	**0.033**	8.659	**0.034**
Caries	6.808	0.078	6.382	0.094
DEH	1.786	0.618	0.776	0.855
Attrition[a]	7.746	0.052	8.064	**0.045**
Periodontal disease	4.666	0.198	-	-
Calculus	6.959	0.641	-	-

P≤0.05, [a]advanced (grades 7 and 8).

No periodontal disease was noted in the 9 males from Hissar I (0%). Periodontal disease was more common among Hissar II males (40%), but this decreased to 23% for the Hissar III period (insignificant).

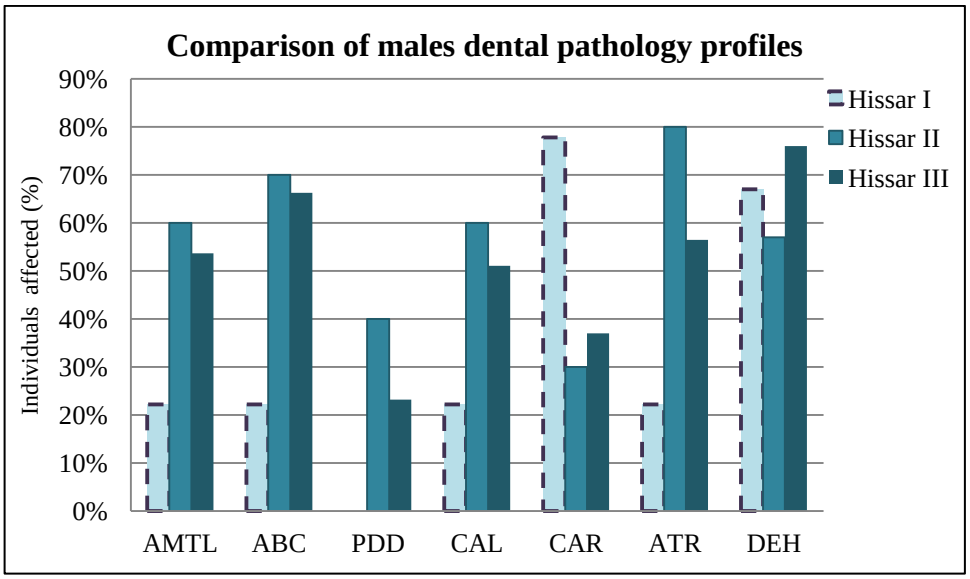


Fig 7.83. Male dental pathology profiles at Tepe Hissar, by period (Individuals affected)

The prevalence rate of caries was the highest among males for Hissar I (78%) and an average of 1.7 teeth per person were affected, but this decreased to 30% in Hissar II (0.4 teeth per person), and then increased to 37% in Hissar III (0.8 teeth per person) (insignificant). The frequency rate of calculus in Hissar II males was higher (60%) than the 51% recorded for Hissar III (22%). The lowest rate was seen in Hissar I males (22%) (insignificant). The prevalence rate for attrition was the lowest among males of Hissar I. However, males from Hissar II showed the highest % of attrition, which decreased in Hissar III (significant, teeth affected). In summary, only periapical lesions and attrition in males showed changes over time.

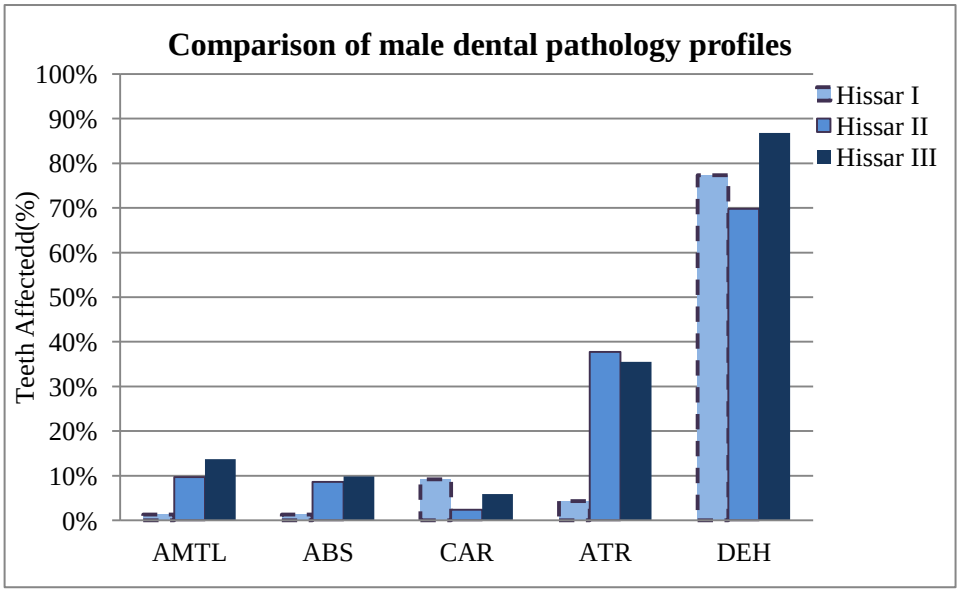


Fig 7.84. Male dental pathology profiles at Tepe Hissar, by period (Teeth Affected)

(*b) Comparison of dental pathology profiles for females at Tepe Hissar, by period*

A comparative analysis of dental disease profiles in female individuals for the different periods at *Tepe Hissar* is illustrated in Table 7.61, Figures 7.85 and 7.86. Females from Hissar I showed the lowest prevalence rate of dental disease compared to the females from other periods. The prevalence rate of AMTL was the lowest among females from Hissar I (38%; 0.9 teeth per person), but in Hissar II it increased sharply to 75% (4.6 teeth per person), and then in Hissar III decreased to 43% (2.3 teeth per person) (insignificant). The prevalence of periapical lesions was the lowest among females of Hissar I (0.2 alveoli per person), but increased dramatically to 63% in Hissar II period (2.2 alveoli per person), and then declined to 56% in Hissar III (1.7 alveoli per person). In the count of the number of teeth affected this pattern was similar to the number of individuals affected (insignificant).

Table 7.61. Comparison of dental pathology profiles for females at Tepe Hissar by period

Dental disease	Individuals affected		Teeth/tooth sockets affected	
	X^2	P	X^2	P
AMTL	5.814	0.121	7.779	0.123
Periapical lesions	6.090	0.107	6.072	0.108
Caries	7.113	0.068	4.807	0.186
DEH	3.377	0.337	0.643	0.886
Attrition[a]	6.009	0.111	4.416	0.220
Periodontal disease	4.034	0.258	-	-
Calculus	5.996	0.740	-	-

$P \leq 0.05$, [a]advanced (grades 7 and 8).

The females from Hissar II showed the highest prevalence of periodontal disease (25%), compared to females from Hissar III (12%). However, no periodontal disease was noted in the eight females from Hissar I (0/8(0%)) (insignificant). The highest prevalence of calculus was recorded from the females of Hissar III period (56%) and the lowest rate was seen in females from Hissar I (25%) (insignificant).

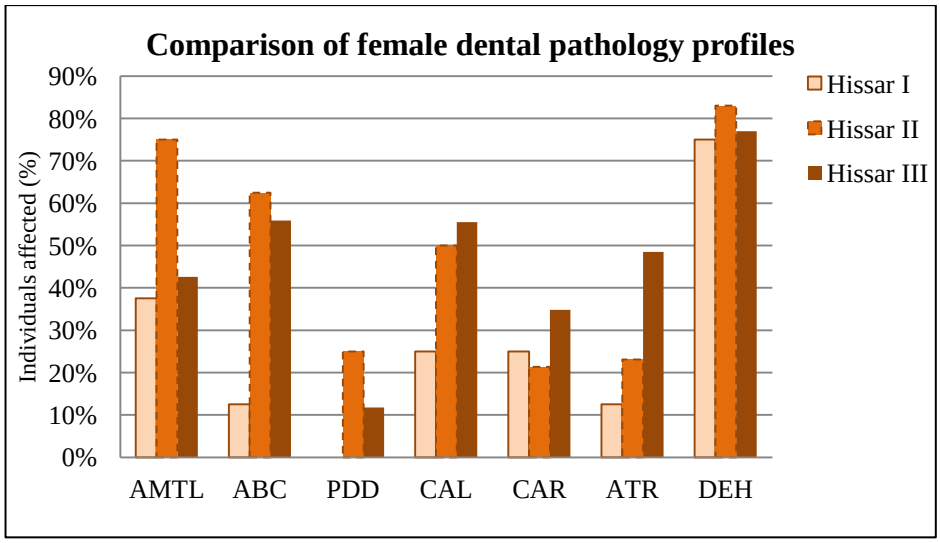


Fig 7.85. Female dental pathology profiles at Tepe Hissar, by period (Individuals affected)

The prevalence of caries was 25% among females from Hissar I (0.2 teeth per individual), a slight decrease of 4% at Hissar II (21%) (0.3 teeth per individual), followed by an increase in Hissar III (35%) which had the highest rate (0.8 teeth per individual) (insignificant). In the teeth affected count, however, the prevalence of caries in Hissar I (2%) was identical to that in Hissar II (2%). The number of teeth affected with caries was 4% higher in Hissar III (insignificant). The highest prevalence rate of attrition was recorded in Hissar III both in individuals (49%) and teeth (19%), while the females from Hissar I showed the lowest rate of attrition (13% and 1%, by individuals and teeth affected, respectively) (insignificant). In summary, all dental pathologies in females showed no significant changes over time.

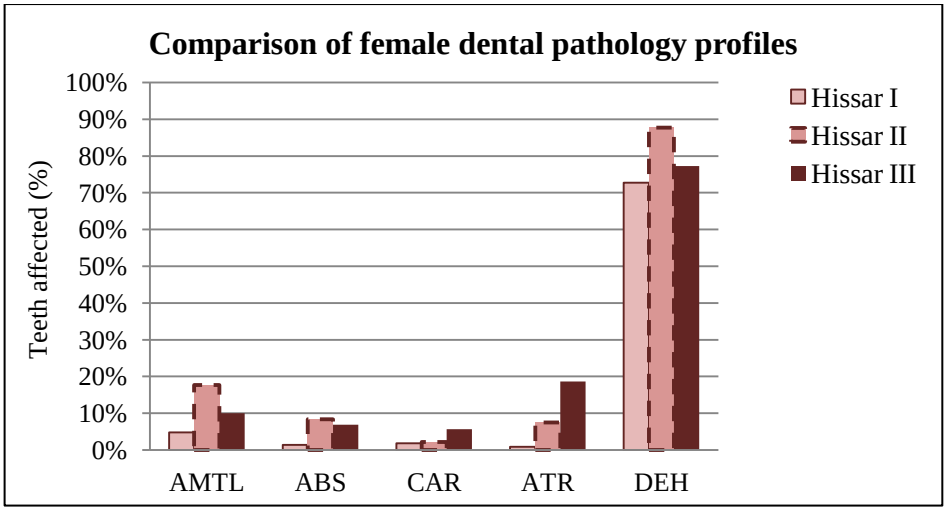


Fig 7.86. Female dental pathology profiles at Tepe Hissar, by period (Teeth affected)

(c) Comparison of dental pathology profiles for unsexed individuals at Tepe Hissar, by period

A comparative analysis of dental disease profiles in unsexed individuals for the different periods at *Tepe Hissar* is illustrated in Table 7.62. The sample size of unsexed individuals is very small particularly in Hissar I and II. The individuals from Hissar III showed caries (17%) and periapical lesions (33%), but two individuals from Hissar I and II did not show those lesions (insignificant).

Table 7.62. Comparison of dental pathology profiles for unsexed individuals at Tepe Hissar by period

Dental disease	Individuals affected		Teeth/tooth sockets affected	
	X^2	*P*	X^2	*P*
AMTL	-	-	-	-
Periapical lesions	0.889	0.641	0.762	0.683
Caries	0.381	0.827	0.333	0.840
DEH	0.743	0.860	0.643	0.986
Attrition[a]	2.000	0.368	3.145	0.207
Periodontal disease	-	-	-	-
Calculus	8.222	0.084	-	-

P≤0.05, [a]advanced (grades 7 and 8).

(d) Comparison of dental pathology profiles of the Tepe Hissar population- Between periods

A summary of the comparative analysis of dental disease profiles for the adult individuals from different periods at *Tepe Hissar* is illustrated in Table 7.63, Figure 7.87 and 7.88. The individuals from Hissar I had the lowest rate of AMTL, periapical lesions, periodontal disease, calculus and attrition, except for caries where the highest rate was seen. The number of teeth affected also shows the lowest rate for Hissar I.

Table 7.63. Comparison of dental pathology profiles for Tepe Hissar population by pooled sex

Dental disease	Individuals affected		Teeth/tooth sockets affected	
	X^2	*P*	X^2	*P*
AMTL	6.877	0.076	7.260	0.640
Periapical lesions	14.008	**0.003**	14.635	**0.002**
Caries	5.762	0.124	4.026	0.259
DEH	1.608	0.658	0.496	0.780
Attrition[a]	7.258	0.064	7.039	0.071
Periodontal disease	7.686	**0.050**	-	-
Calculus	8.140	0.520	-	-

$P \leq 0.05$, [a]advanced (grades 7 and 8).

However, in Hissar II, the rate of all dental diseases increased, but caries rate decreased. Similar changes in the rates of dental diseases in Hissar II by teeth affected were also seen. Individuals from Hissar III had a slightly higher rate of attrition, caries and calculus compared to those from Hissar II, but the rates of periapical lesions, AMTL and periodontal diseases showed a decrease.

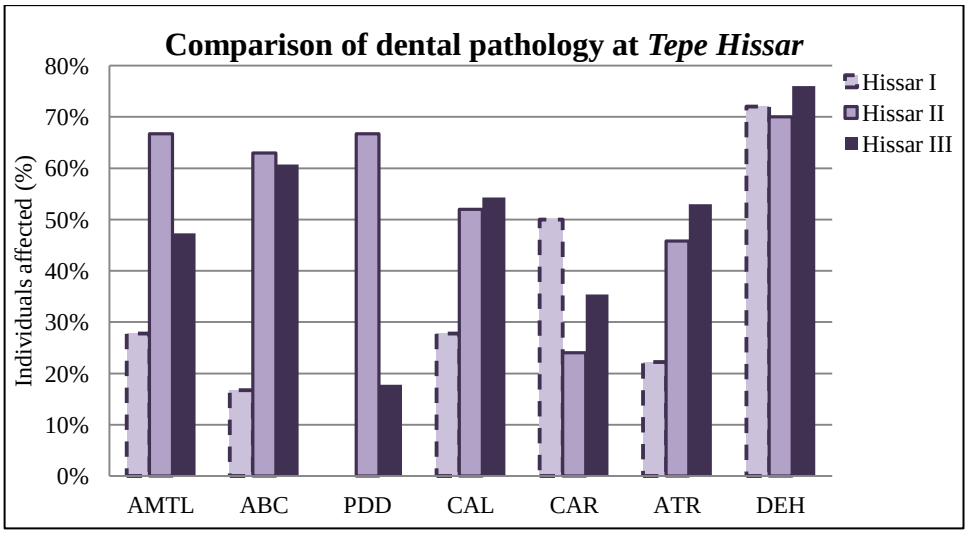


Fig 7.87. Comparison of dental pathology profiles at Tepe Hissar, pooled sex (Individuals affected)

However, rates for both individuals and teeth affected showed no significant differences between the different periods, except for periodontal disease (by individuals affected) and periapical lesions (by individuals and alveoli affected).

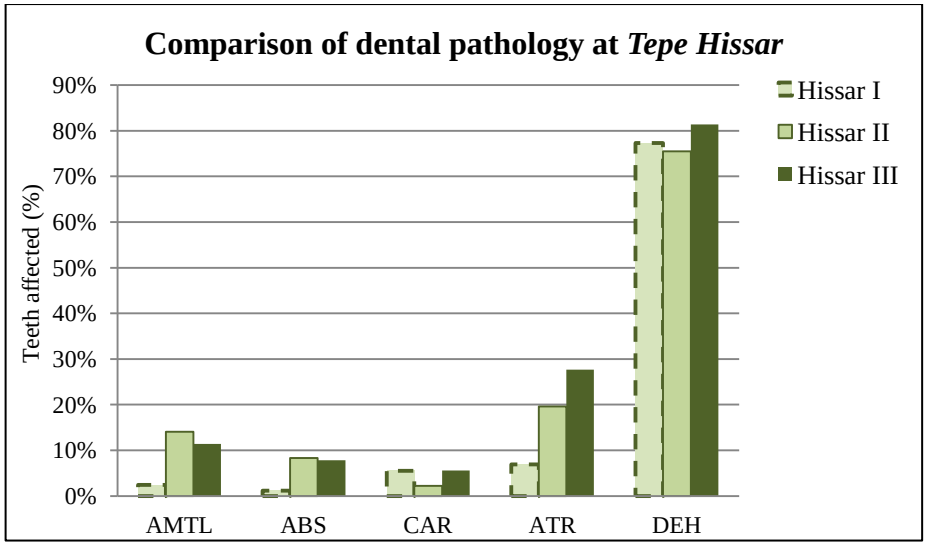


Fig 7.88. Comparison of dental pathology profiles at Tepe Hissar, pooled sex (Teeth affected)

7.6.4. Cranial Trauma

A total of 129 adult crania from three periods at *Tepe Hissar* were examined for identifying evidence for cranial injury representing interpersonal violence. Table 7.64 and Figure 7.90 show the numbers examined and the frequency of ante-and peri-mortem cranial injury among females and males from the three periods. No statistic analysis was employed for this section, because of small samples in Hissar I and II.

Table 7.64. Distribution of ante- and peri-mortem cranial trauma at Tepe Hissar by sex and period

Cranial trauma	**Hissar I**		**Hissar II**		**Hissar III**		**Total**		
	Male (n=1)	*Female* (n=1)	*Male* (n=7)	*Female* (n=10)	*Male* (n=67)	*Female* (n=43)	**Hissar I**	**Hissar II**	**Hissar III**
Peri-mortem	0(0%)	1(100%)	2(28.5%)	2(20%)	12(18%)	8(18.6%)	50%	23.5%	18%
Healing	0(0%)	0(0%)	0(0%)	1(10%)	3(4.5%)	0(0%)	0%	6.0%	2.7%
Healed	0(0%)	0(0%)	1(14.3%)	2(20%)	18(27%)	10(23%)	0%	17.6%	25.4%
Total	0(0%)	1(100%)	3(42.8%)	5(50%)	33(49%)	18(42%)	50%	47%	46%

In Hissar I, one female presented evidence of cranial peri-mortem injury (Figure 7.89).

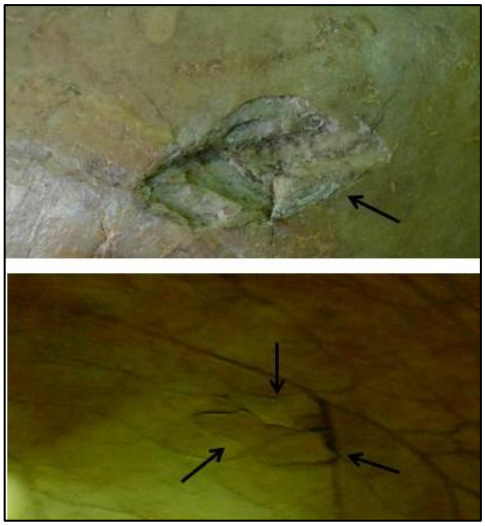


Fig 7.89. Hissar I: Peri-mortem blunt force trauma of skull vault (parietal bone)- upper, with some parts of bone from the fracture displaced endocranially (Sk 33-23-7)

Generally the frequency of cranial trauma was higher among females from Hissar II compared to males, but the prevalence of peri-mortem trauma was higher in males than females. In Hissar III males showed a higher rate of healed cranial injury compared to females, but the rate of lethal head trauma was higher for females in this period.

Comparing the total prevalence of cranial trauma in each period (Figure 7.90), the Hissar II group (47%) exhibited a marginally higher prevalence compared to Hissar III (46%). The percentage for lethal cranial injury was higher in Hissar II (23.5%) compared to Hissar III (18%); the rate was 50% for Hissar I, but the sample size is not adequate to estimate rates. In the Hissar II period the frequency of injuries with evidence of healing was also higher (6%) than in Hissar III (3%). This may indicate that some individuals were suffering injuries at the time of death, or possibly their death may have been caused by cranial injury. In contrast, the frequency of healed cranial injuries was higher in Hissar III (25%) compared to Hissar II (18%).

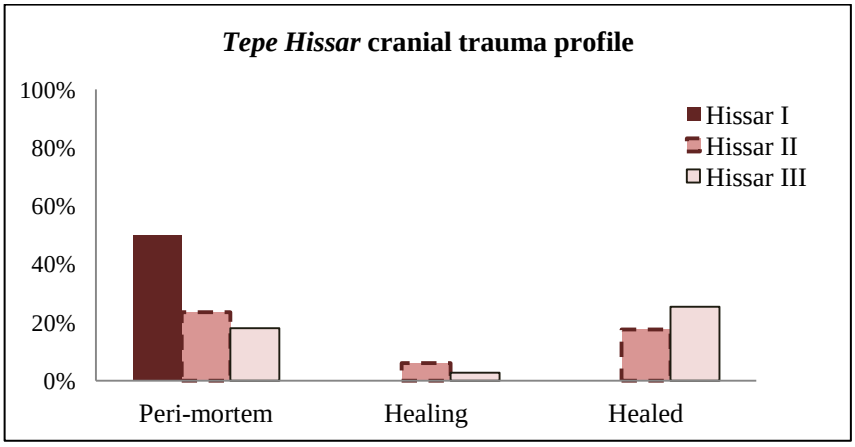


Fig 7.90. Cranial injury profile for the Tepe Hissar population

Comparison of the frequency of ante- and peri-mortem cranial injuries among the different adult age-categories at *Tepe Hissar* is shown in Table 7.65. In both Hissar II and III the evidence of peri-mortem injury was seen across different age-groups, but in Hissar III, MA males (42%) and females (40%) had a higher prevalence compared to the other age-groups. The YA1 (11.8%) and YA2 (12.5%) females from Hissar III exhibited a higher frequency of peri-mortem injuries compared to males (5.6% and 7.4%, respectively).

The distribution pattern of ante-mortem head trauma indicates a higher prevalence in YA2 and MA females from Hissar II than in males from these age-groups, and in Hissar III males and females showed very different frequencies. Cranial injury was recorded with a higher frequency for YA1 (11%) and YA2 (33.3%) males compared to females (5.9%, 18.8%, respectively). In contrast, MA females exhibited the highest frequency of cranial injury (60%) compared to males (42%) and the younger adult age-groups for both sexes.

Table 7.65. Distribution of ante- and peri-mortem cranial trauma at Tepe Hissar by age-category and period

Age-category	Hissar I		Hissar II		Hissar III	
	Male	Female	Male	Female	Male	Female
Peri- mortem						
YA 1	-	1(100%)	-	1(25%)	1(5.6%)	2(11.8%)
YA 2	-	-	1(20%)	1(20%)	2(7.4%)	2(12.5%)
MA	-	-	-	-	8(42%)	4(40%)
OA	-	-	1(100%)	-	1(33%)	-
Ante-mortem (healed-healing)						
YA 1	-	-	-	-	2(11%)	1(5.9%)
YA 2	-	-	1(20%)	2(40%)	9(33%)	3(18.8%)
MA	-	-	-	1(100%)	8(42%)	6(60%)
OA	-	-	-	-	2(67%)	-

Table 7.66 shows the distribution of ante- and peri-mortem cranial injuries based on their location. The frequency of frontal bone trauma was higher in Hissar II (male 14%, female 20%) compared to Hissar III (male 5%, female 9%). In contrast, in Hissar III parietal bone injuries were more prevalent (male 33%, female 28%), and one individual had occipital bone trauma (2%). There was evidence of trauma on the orbital (3%) and nasal (2%) bones in individuals from Hissar III. Some individuals from Hissar II and III exhibited more than one cranial injury (between 1 and 3 injuries) which was higher in frequency in individuals from Hissar II. The frequency for frontal bone trauma was greater among females compared to males. However, males had a higher frequency of injury to the parietal bones compared to females.

Table 7.66. Distribution of cranial ante- and peri-mortem trauma by location of the injury

Location	Hissar I		Hissar II		Hissar III	
	Male	Female	Male	Female	Male	Female
Frontal	-	-	14%	20%	5%	9%
Parietal	-	100%	14%	10%	33%	28%
Occipital	-	-	-	-	-	2%
Nasal	-	-	-	-	2%	-
Orbital	-	-	-	-	3%	-
>1 cranial injury	-	-	14%	20%	9%	5%

There were a total of 35 individuals (Hissar II, III) who exhibited ante-mortem cranial trauma, and all variously displayed round, elliptical, or linear depression (nasal and orbital) fractures, suggesting a pattern of blunt force injury. However, from a total of 25 individuals with evidence of peri-mortem cranial injury, 16 exhibited blunt force trauma, three showed sharp force, and seven had puncture wounds (Table 7.67, Figures 7.91 and 7.92). The frequency of blunt force trauma was higher at *Tepe Hissar* compared to sharp and puncture force trauma, and at a higher rate in individuals from Hissar III (60%) compared to Hissar II (50%). The only female from Hissar I had a peri-mortem injury related to blunt force trauma (100%). One of the individuals from Hissar II (25%) and two from Hissar III (10%) exhibited sharp force trauma. Evidence of puncture wounds was more frequent in Hissar III with six individuals exhibiting this type of injury (30%) (Figure 7.93). The majority of peri-mortem cranial injuries affected parietal bones, with a frequency of over 75%, but the frequency for frontal bone injury was less than 25%.

Table 7.67. Distribution of ante- and peri-mortem cranial trauma at Tepe Hissar by type of force

Periods	Ante-mortem	Peri-mortem		
	Blunt	Blunt	Sharp	Puncture
Hissar I	-	1/1 (100%)	0/1 (0%)	0/1 (0%)
Hissar II	4/4 (100%)	2/4 (50%)	1/4 (25%)	1/4 (25%)
Hissar III	31/31(100%)	12/20 (60%)	2/20 (10%)	6/20(30%)

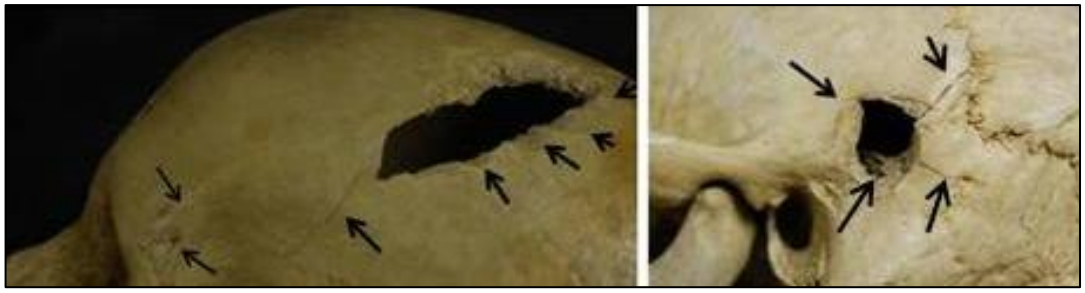


Fig 7.91. Left: Hissar II:sharp-force trauma (left parietal Sk33-23-22)- probable sword or dagger wound with "peeling" of the lateral edge; Right:puncture-force trauma of left temporal bone near the mastoid process (Sk33-23-36)

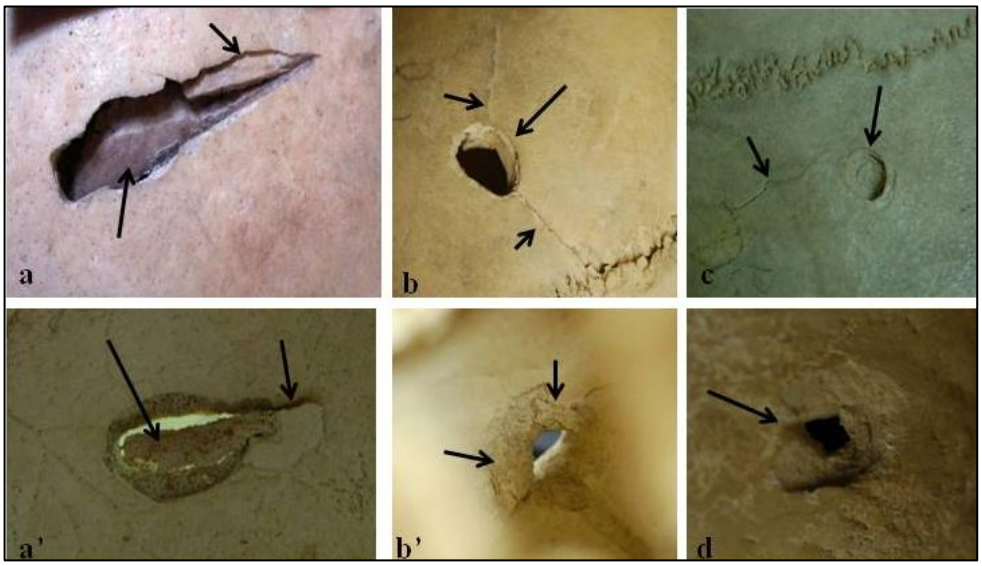


Fig 7.92. Some examples of peri-mortem cranial trauma from Hissar III (a,a'): right parietal bone (32x7mm) with some parts of bone from the fracture displaced endocranially-Sk 33-23-179; (b,b'): right frontal bone (13x7mm) with some parts of bone displaced endocranially-Sk 33-23-197;(c):left parietal bone (9x6mm)- Sk 33-23-107; (d): left parietal bone (5x5mm)-Sk 33-23-152

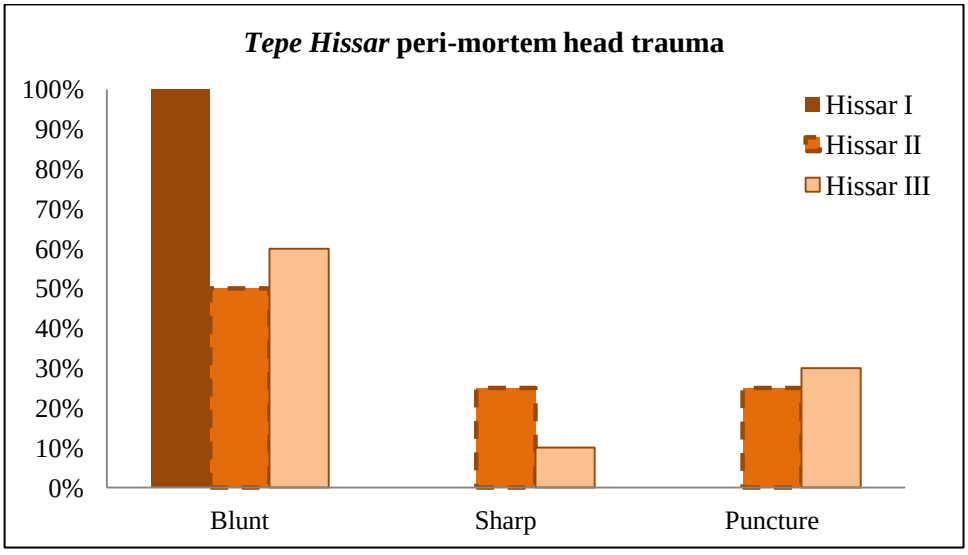


Fig 7.93. Distribution of peri-mortem cranial trauma at Tepe Hissar

7.6.5. Carbon and Nitrogen Stable Isotope Ratios

The results of the isotopic measurements and basic descriptions of the individuals analysed are displayed in Table 7.68. This is the first stable isotopic data for Chalcolithic and Bronze Age populations from the Central Iranian Plateau.

In the following sections the dietary differences between individuals from *Tepe Hissar* are examined. Statistical analyses and plots of $\delta^{13}C$ versus $\delta^{15}N$ are presented for $\delta^{13}C$ and $\delta^{15}N$ collagen values between males and females by period, between different age groups by period, and between periods by pooled sex. The possibility of effect of social complexity or cultural buffering on individual's diet was evaluated by comparison between isotopic values and numbers of grave goods by sex and period.

The human bone samples were well preserved. Of 69 samples analysed, 68 yielded collagen of sufficient quality with only one sample from Hissar III rejected due to a yield of less than 1 wt% (Ambrose, 1990). All 68 samples produced C:N ratios between 3.1 to 3.5, within the accepted range 2.9 to 3.6 (DeNiro, 1985). The percentage of both carbon and nitrogen is between accepted ranges 35-50 wt% and 11-16 wt% respectively, indicating good quality collagen (van Klinken, 1999).

Table 7.68. Samples and isotopic results for carbon and nitrogen at Tepe Hissar

Sample no.*	Square	Sk no.	Period	Sex[1]	Age[2] (year)	Bone	Collagen yield (wt.%)	$\delta^{13}C_{VPDB}$ (‰)	$\delta^{15}N_{AIR}$ (‰)	C:N	C (wt.%)	N (wt.%)
Hissar I *(n=8)*												
A7	CG95	16	I	M	18-25	Humerus	10.9	-19.5	11.1	3.3	44.1	15.6
A23	DH21	12	I	M	26-35	Femur	10.4	-19.2	12.0	3.2	42.7	15.4
A18	DG69	16	I	M	18+	Tibia	12.7	-19.9	10.9	3.3	44.0	15.4
A17	DG69	8	I	F	18-25	Femur	9.4	-20.0	11.3	3.2	42.0	15.6
A9	DG36	2	I	F	18+	Femur	11.1	-19.9	12.1	3.2	42.3	15.3
A5	CG95	8	I	F	18+	Tibia	11.4	-19.7	12.5	3.2	42.5	15.5
A2	CG95	4	I	F	18-25	Tibia	8.6	-19.7	11.8	3.3	44.1	15.8
A20	DG96	8	I	I	18+	Humerus	11.4	-20.4	13.1	3.3	41.8	14.8
Hissar II *(n=11)*												
A36	CG25	20	II	M	18+	Humerus	7.4	-20.1	11.4	3.1	42.0	15.6
A35	CG25	13	II	M	18+	Femur	11.8	-19.2	11.7	3.2	42.2	15.6
A34	CG25	5	II	M	18+	Humerus	8.8	-20.1	13.5	3.2	42.0	15.3
A32	CG25	1	II	M	36-50	Femur	13.3	-18.9	12.5	3.2	41.9	15.4
A121	DF29	5	II	M	36-50	Radius	9.1	-19.2	13.4	3.2	44.0	15.9
A128	DF29	28	II	F	18-25	Femur	10.1	-19.8	13.1	3.2	41.2	15.1
A38	CG25	23	II	F	18+	Femur	15	-19.8	10.8	3.2	42.1	15.2
A29	DG96	1	II	F	18+	Femur	13.4	-19.1	12.7	3.2	42.8	15.7
A39	CG60	4	II	F	18-25	Humerus	6.9	-20.2	12.7	3.3	42.4	15.2
A42	DG96	22	II	F	26-35	Femur	13.4	-19.3	10.6	3.2	42.5	15.6
A33	CG25	4	II	I	18+	Tibia	11.4	-19.4	11.8	3.3	42.0	14.9
Hissar III *(n=49)*												
A101	DF19	29	III	M	18+	Femur	8.6	-19.1	11.8	3.4	42.6	14.9
A143	DG10	7	III	M	36-50	Femur	13.6	-18.9	13.0	3.1	41.9	15.6
A66	DF18	9	III	M	26-35	Femur	13.3	-19.8	12.6	3.1	41.9	15.6
B158	CH86	4	III	M	50+	Femur	14.3	-20.4	11.8	3.3	41.7	14.8
A70	DF18	15	III	M	18-25	Femur	13.9	-20.4	14.1	3.5	43.8	14.8
A79	DF18	38	III	M	26-35	Femur	9.5	-19.6	11.9	3.2	41.7	15.3
B102	DG11	16	III	M	26-35	Femur	11	-19.0	13.1	3.2	42.3	15.4
B110	DG20	18	III	M	26-35	Femur	7.3	-20.1	12.9	3.2	41.8	15.4
B111	DG20	21	III	M	36-50	Femur	11	-19.8	12.3	3.2	41.7	15.2
B76	CG90	4	III	M	26-35	Femur	11	-19.9	11.9	3.2	42.4	15.4
B80	CG90	23	III	M	18+	Femur	11	-18.6	13.3	3.3	44.7	15.6
A98	DF19	23	III	M	18+	Tibia	7.3	-19.5	13.9	3.3	43.3	15.4
A71	DF18	16	III	M	36-50	Femur	11.6	-19.8	11.8	3.3	43.8	15.7

A133	DG00	1	III	M	36-50	Femur	10.3	-19.3	12.5	3.2	43.7	15.8
A60	DF09	1	III	M	18+	Femur	13.4	-18.4	12.6	3.3	44.1	15.5
B120	CG90	1	III	M	36-50	Femur	15	-19.8	10.7	3.3	44.1	15.6
A117	DF29	1b	III	M	26-35	Femur	13.7	-19.8	11.8	3.1	41.8	15.5
B103	DG11	32	III	M	18+	Femur	14.4	-20.2	12.4	3.4	44.1	15.0
A124	DF29	8	III	M	36-50	Femur	14	-19.8	13.4	3.3	44.1	15.4
A135	DG00	4	III	M	18+	Femur	10.2	-19.8	12.3	3.3	44.5	15.8
A181	DF18	17	III	M	18+	Femur	12.2	-19.2	12.5	3.3	44.1	15.5
A118	DF29	2	III	M	26-35	Humerus	14.7	-20.0	11.7	3.1	42.3	15.7
B116	CF79	1	III	M	18+	Femur	15	-19.7	12.5	3.4	43.6	15.2
A45	EG06	5	III	M	18+	Tibia	11.6	-19.9	11.2	3.2	42.4	15.7
A205	DG00	8	III	F	26-35	Femur	16.8	-20.2	12.1	3.2	41.5	15.3
A141	DG00	22	III	F	36-50	Femur	12.5	-19.5	11.1	3.2	41.8	15.5
A182	DF18	18	III	F	36-50	Femur	11.5	-20.3	12.6	3.2	41.4	15.1
A206	DG00	8	III	F	26-35	Femur	14.9	-19.9	12.5	3.2	41.8	15.2
A81	DF18	39a	III	F	36-50	Femur	13.2	-20.0	11.5	3.2	42.1	15.2
A94	DF19	17	III	F	18+	Femur	11.2	-19.8	13.1	3.2	42.0	15.4
A95	DF19	19	III	F	36-50	Femur	13.6	-19.8	12.2	3.2	42.6	15.3
B185	DG01	15	III	F	36-50	Tibia	13.8	-19.3	13.0	3.3	41.7	14.9
B226	DG20	17	III	F	18-25	Femur	12	-20.1	11.0	3.2	41.9	15.2
A110	DF19	55	III	F	26-35	Femur	12.7	-19.7	11.8	3.1	41.4	15.5
A99	DF19	24	III	F	36-50	Humerus	11.4	-18.7	12.8	3.2	41.9	15.2
A136	DG00	5	III	F	26-35	Femur	9.2	-19.9	12.6	3.2	42.9	15.5
A87	DF19	4	III	F	18+	Femur	12.9	-19.8	13.1	3.2	41.8	15.3
A97	DF19	21	III	F	36-50	Femur	11	-18.1	12.8	3.2	42.3	15.6
B101	DG01	38	III	F	18+	Femur	7.3	-19.7	12.3	3.1	41.8	15.5
B58	CF55	1	III	F	18+	Femur	7.3	-19.6	12.4	3.2	42.1	15.4
B79	CG90	15	III	F	26-35	Humerus	7.3	-20.0	11.9	3.3	42.9	15.1
A89	DF19	7	III	F	18-25	Femur	13.5	-19.9	11.4	3.3	44.5	15.7
A167	DG00	19	III	F	18+	Tibia	13.8	-19.0	8.8	3.2	43.6	15.8
B119	CG80	2	III	F	18-25	Femur	14.1	-19.5	11.9	3.2	43.1	15.6
B122	CH64	2	III	F	18+	Femur	13.6	-19.7	10.6	3.3	44.2	15.9
B106	DG11	52	III	F	18-25	Femur	15	-20.2	12.0	3.4	43.4	15.1
B178	DG01	1	III	F	18+	Femur	11	-20.0	13.2	3.3	43.9	15.3
A204	DG00	7	III	I	18+	Tibia	11.8	-19.9	11.9	3.1	42.4	15.8
A47	EG06	29	III	F	26-35	Femur	9.9	-19.5	11.8	3.6	45.7	15.0

[1]M=Male, F=Female, and I=Indeterminate

[2]YA1=18-25, YA2=26-35, MA=36-50, OA=50+, AA=18+

*A= Museum no 33-16-sk. no., B= Museum no 33-23-sk. no. (e.g., 33-16-20, 33-23-185)

(i) Carbon and Nitrogen Stable Isotope Values by Period

(a)Hissar I

The summary data are presented in Tables 7.69 and 7.70. There was little variation in both $\delta^{13}C$ and $\delta^{15}N$ values among individuals. Comparison between the sexes, showed males having slightly more positive $\delta^{13}C$ values (0.3‰) than females, in contrast females showed a slight enrichment in $\delta^{15}N$ value (0.6‰) compared to males. These differences between males and females were not significant ($\delta^{13}C$ *U*=3, *p*=0.289, $\delta^{15}N$ *U*=2, *p*=0.157).

Table 7.69. Hissar I descriptive statistics for isotopic values by sex

Individuals	*Mean $\delta^{13}C$‰*	*SD*	*Range‰*	*Mean $\delta^{15}N$‰*	*SD*	*Range‰*
Male (n=3)	-19.5	0.34	-19.9 to -19.2	11.3	0.59	10.8-12.0
Female (n=4)	-19.8	0.15	-20.0 to -19.6	11.9	0.53	11.3-12.5
Indeterminate (n=1)	-20.4	-	-	13.1	-	-
All	-19.8	0.36	-20.4 to -19.2	11.8	0.76	10.9-13.1

There was a small difference in diet between YA1 and YA2 (Table 7.70). YA2 sample showed higher $\delta^{13}C$ and $\delta^{15}N$ values (0.5‰ and 0.6‰) compared to YA1 samples respectively. However, the small sample size should be considered. No significant differences were found between individuals of different age-groups ($\delta^{13}C$ K-W=3.208, *p*=0.201, $\delta^{15}N$ K-W=1.833, *p*=0.400).

Table 7.70. Hissar I descriptive statistics for isotopic values by age-group

Age-group	*No.*	*Mean $\delta^{13}C$‰*	*SD*	*Range‰*	*Mean $\delta^{15}N$‰*	*SD*	*Range‰*
YA1 (18-25)	3	-19.7	0.26	-20.0 to -19.4	11.4	0.35	11.0-11.7
YA2 (26-35)	1	-19.2	-	-	12.0	-	-
MA (36-50)	0	-	-	-	-	-	-
OA (50+)	0	-	-	-	-	-	-
AA (18+)	4	-20.0	0.32	-20.4 to -19.7	12.1	0.96	10.8-13.1

Figure 7.94 shows plot of $\delta^{13}C$ versus $\delta^{15}N$ for eight individuals. There were two individuals who exhibited more positive values for $\delta^{15}N$ (A5 (12.5‰) and A20 (13.1‰)) compared to the others. The $\delta^{13}C$ values for these individuals were -19.7‰ and -20.4‰, respectively (Table 7.68).

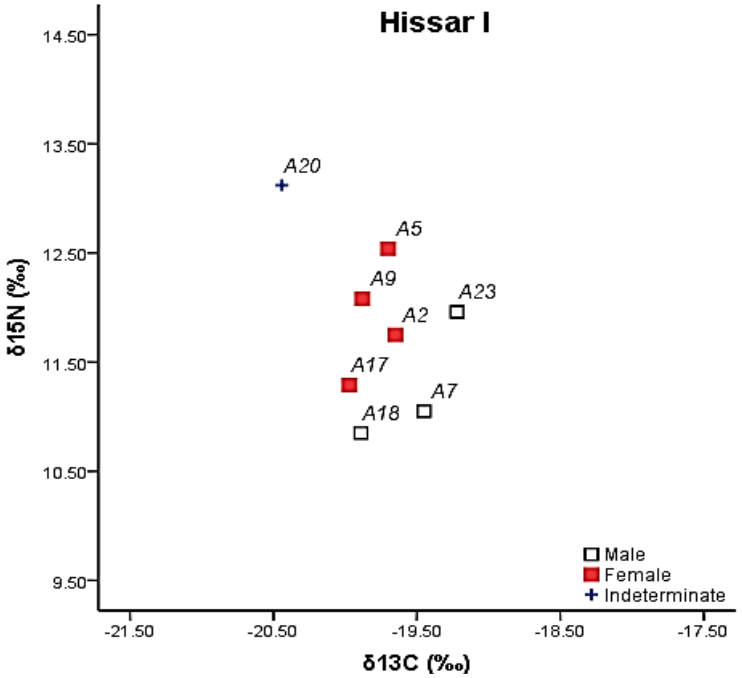


Fig 7.94. Carbon and nitrogen stable isotope ratios of bone collagen from Hissar I, by sex

(b) Hissar II

The summary data are presented in Tables 7.71 and 7.72. There is little sex difference in diet in this period. Males had marginally higher $\delta^{13}C$ (0.1‰) and $\delta^{15}N$ (0.5‰) values compared to females. The $\delta^{15}N$ values showed a marginally wider range among females compared to males. These differences between the sexes were not significant ($\delta^{13}C$ *U*=10, *p*=0.602, $\delta^{15}N$ *U*=9, *p*=0.465).

Table 7.71. Hissar II descriptive statistics for isotopic values by sex

Individuals	*Mean $\delta^{13}C$‰*	*SD*	*Range‰*	*Mean $\delta^{15}N$‰*	*SD*	*Range‰*
Male (n=5)	-19.5	0.56	-20.1 to -18.9	12.5	0.97	11.4-13.5
Female (n=5)	-19.6	0.43	-20.1 to -19.1	12.0	1.17	10.6-13.1
Indeterminate(n=1)	-19.4	-	-	11.8	-	-
All	-19.5	0.46	-20.1 to -18.9	12.2	1.0	10.6-13.5

The data showed a small difference in carbon and nitrogen values between different age-groups. For example, MA individuals showed higher $\delta^{13}C$ and $\delta^{15}N$ values compared to YA1 and YA2 (Table 7.72). However, these differences were not significant ($\delta^{13}C$ *K-W*=5.288, *p*=0.152, $\delta^{15}N$ *K-W*=4.379, *p*=0.223).

Table 7.72. Hissar II descriptive statistics for isotopic values by age-group

Age-group	*No.*	*Mean $\delta^{13}C$‰*	*SD*	*Range‰*	*Mean $\delta^{15}N$‰*	*SD*	*Range‰*
YA1 (18-25)	2	-20.0	0.23	-20.1 to -19.8	12.9	0.26	12.7-13.1
YA2 (26-35)	1	-19.3	-	-	10.6	-	-
MA (36-50)	2	-19.0	0.21	-20.1 to -18.9	12.9	0.68	12.5-13.4
OA (50+)	-	-	-	-	-	-	-
AA (18+)	6	-19.6	0.43	-20.1 to -19.1	12.0	0.96	10.8-13.5

Figure 7.95 shows $\delta^{13}C$ versus $\delta^{15}N$ for the eleven individuals from this period. Six individuals (3 males- 3 females) had a slightly more positive $\delta^{15}N$ value (from 12.5‰ to 13.5‰) compared to the other five samples (from 10.6‰ to 11.8‰). The $\delta^{13}C$ values for these individuals were between -20.1‰ and-18.9‰ (Table 7.68).

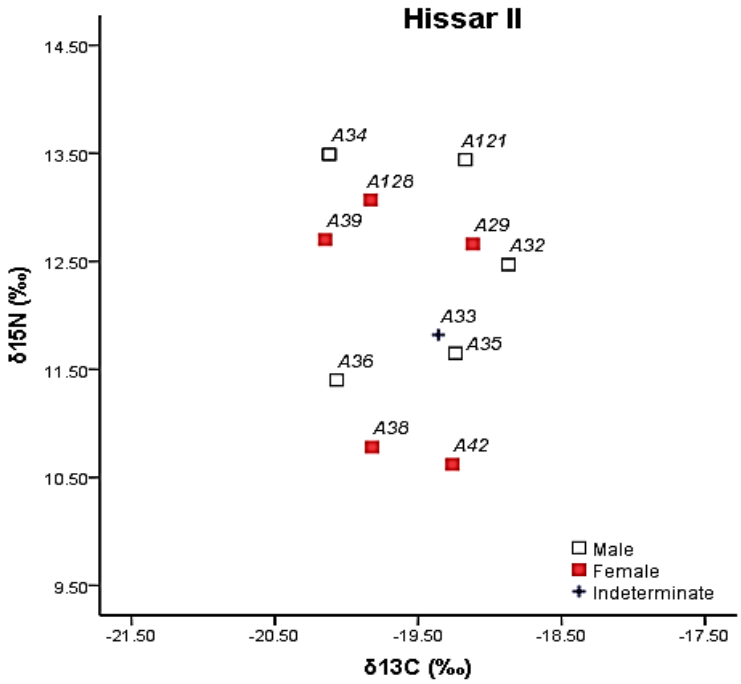


Fig 7.95. Carbon and nitrogen stable isotope ratios of bone collagen from Hissar II, by sex

(c) Hissar III

The average $\delta^{13}C$ and $\delta^{15}N$ values are presented in Table 7.73. The variability in $\delta^{15}N$ values was slightly more pronounced in females (4.4‰) than males (3.4‰).

Table 7.73. Hissar III descriptive statistics for isotopic values by sex

Individuals	*Mean $\delta^{13}C$‰*	*SD*	*Range‰*	*Mean $\delta^{15}N$‰*	*SD*	*Range‰*
Male (n=24)	-19.6	0.52	-20.4 to -18.4	12.4	0.8	10.7-14.1
Female (n=24)	-19.7	0.51	-20.2 to -18.1	12.0	1.0	8.8-13.2
Indeterminate (n=1)	-19.9	-	-	11.9	-	-
All	-19.6	0.50	-20.4 to -18.1	12.2	0.9	8.8-14.1

The data also showed little sex and age difference in diet in Hissar III. The mean values for $\delta^{13}C$ and $\delta^{15}N$ were marginally higher in males (0.1‰ and 0.4‰ respectively) compared to females. The mean $\delta^{13}C$ and $\delta^{15}N$ values increased slightly with increasing age and MA showed higher values than younger individuals. However, one OA individual had the lowest $\delta^{13}C$ and $\delta^{15}N$ values (Table 7.74). Nevertheless, there was no significant difference between the sexes for $\delta^{13}C$ and $\delta^{15}N$ values ($\delta^{13}C$ *U*=249, *p*=0.565, $\delta^{15}N$ *U*=229, *p*=0.317) or between different age-groups ($\delta^{13}C$ *K-W*=7.993, *p*=0.092, $\delta^{15}N$ *K-W*=1.279, *p*=0.865).

Table 7.74. Hissar III descriptive statistics for isotopic values by age-group

Age-group	*No.*	*Mean $\delta^{13}C$‰*	*SD*	*Range‰*	*Mean $\delta^{15}N$‰*	*SD*	*Range‰*
YA1 (18-25)	5	-20.0	0.35	-20.4 to -19.5	12.1	1.19	11.0-14.1
YA2 (26-35)	13	-19.8	0.31	-20.2 to -19.0	12.2	0.49	11.7-13.1
MA (36-50)	13	-19.5	0.58	-20.2 to -18.1	12.2	0.83	10.7-13.4
OA (50+)	1	-20.4	-	-20.4	11.8	-	11.8
AA (18+)	17	-19.5	0.5	-20.2 to -18.4	12.2	1.18	8.8-13.9

Figure 7.96 shows a plot of $\delta^{13}C$ versus $\delta^{15}N$ for 49 individuals from Hissar III. Almost 58% of individuals (male=15, female=13) showed relatively higher $\delta^{15}N$ values, between 12.1‰ and 14.1‰, compared to the rest of the samples. Six of these individuals, in addition to high $\delta^{15}N$ values, exhibited a $\delta^{13}C$ values between -19.0‰ and -18.1‰. The plot shows that in some individuals the increase in $\delta^{15}N$ values was associated with an increase in $\delta^{13}C$ values and a shift to the right section of the plot, while in others it was associated with decrease in $\delta^{13}C$ values and slight shift to the left section of plot. One female (A167) was an outlier with the lowest $\delta^{15}N$ value (8.8‰).

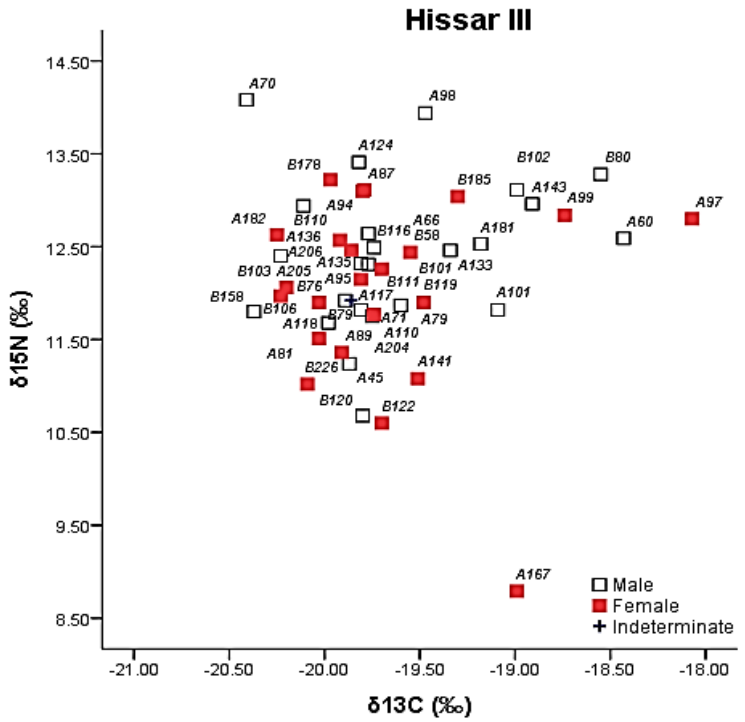


Fig 7.96. Carbon and nitrogen stable isotope ratios of bone collagen from Hissar III, by sex

(ii) Carbon and Nitrogen Stable Isotope ratios: between Periods by Pooled Sex

A comparison of $\delta^{13}C$ versus $\delta^{15}N$ values between periods and by pooled sex at *Tepe Hissar* is illustrated in Figure 7.97 and Table 7.75. In general, the SD for $\delta^{13}C$ values was smaller in Hissar I (0.36) compared to Hissar II (0.46) and Hissar III (0.5). However, the SD $\delta^{15}N$ values were smaller in Hissar I (0.8) compared to Hissar II (1) and Hissar III (0.9).

Table 7.75. Comparison of the isotopic values between periods at Tepe Hissar by pooled sex

Period	*No.*	*Mean $\delta^{13}C$‰*	*SD*	*Range‰*	*Mean $\delta^{15}N$‰*	*SD*	*Range‰*
Hissar I	8	-19.8	0.36	-20.4 to -19.2	11.8	0.76	10.8-13.1
Hissar II	11	-19.5	0.46	-20.1 to -18.9	12.2	1.0	10.6-13.5
Hissar III	49	-19.6	0.50	-20.4 to -18.1	12.2	0.9	8.8-14.1
All	68	-19.6	0.48	-20.4 to -18.1	12.2	0.9	8.8-14.1

The plot (Figure 7.97) shows that, with passing time at *Tepe Hissar*, $\delta^{13}C$ and $\delta^{15}N$ values were shifted more in a positive direction, particularly among Hissar III individuals. Overall, the data shows that, in Hissar II both $\delta^{13}C$ and $\delta^{15}N$ ratios increased slightly (0.2‰ and 0.4‰ respectively) compared to Hissar I, but the mean isotopic signatures for Hissar III stayed almost identical to Hissar II. However, there was no significant difference in both $\delta^{13}C$ and $\delta^{15}N$ values among individuals from the three periods ($\delta^{13}C$ *K-W*=0.644, *p*=0.718, $\delta^{15}N$ *K-W*=1.558, *p*=0.459). Levene's test also did not show any significant differences in variance ($\delta^{13}C$ Levene's test =0.589, *p*= 0.558, $\delta^{15}N$ Levene's test= 0.567, *p*= 0.570).

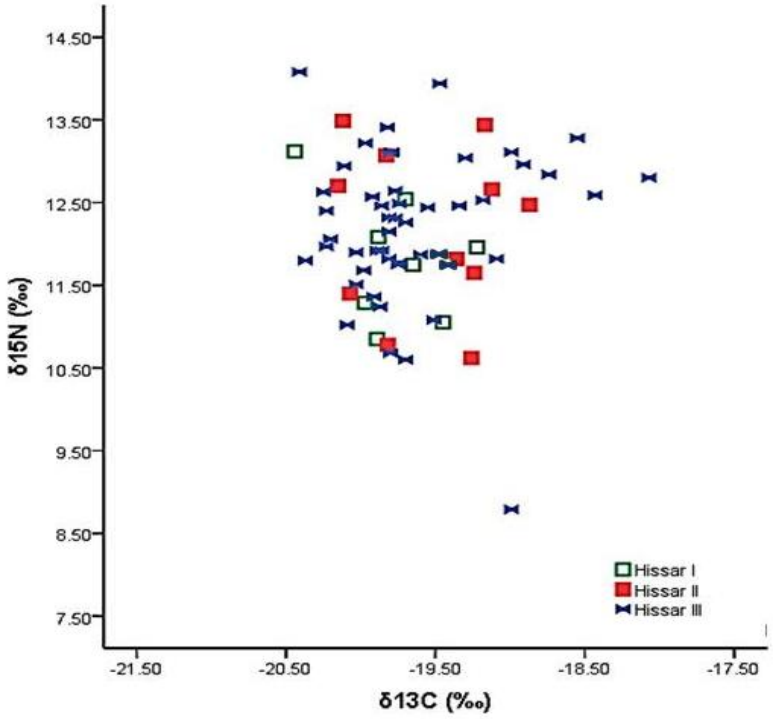


Fig 7.97. A comparison of carbon and nitrogen stable isotope ratios of bone collagen at Tepe Hissar by pooled sex

(iii) Carbon and Nitrogen Stable Isotope Ratios and Social Status

Table 7.76 compares $\delta^{13}C$ and $\delta^{15}N$ values of individuals from the three periods with the number of grave-goods to evaluate potential correlations between diet and social status, and identify individuals with a different diet that may reflect underlying social differences. For example, individuals with a high status may have had greater

access to dietary protein and a better diet than low status individuals. Therefore, a comparison was made for females and males separately within each period based on the number of their grave-goods, but no significant correlation was found between the number of grave-goods and $\delta^{13}C$ and $\delta^{15}N$ values in males or females for any period. (Hissar I males:$\delta^{13}CU$=2.000, *p*=0.368, $\delta^{15}NU$=200, *p*=0.368, females:$\delta^{13}CU$=2700, *p*=0.259, $\delta^{15}NU$=1.800, *p*=0.407; Hissar II males:$\delta^{13}CU$=3.200, *p*=0.202, $\delta^{15}NU$=2.133, *p*=0.344, females:$\delta^{13}CU$=3.800, *p*=0.284, $\delta^{15}NU$=3.800, *p*=0.284; and Hissar III males:$\delta^{13}CU$=5.673, *p*=0.461, $\delta^{15}NU$=5.663, *p*=0.462, females:$\delta^{13}CU$=10.365, *p*=0.240, $\delta^{14}NU$=7.796, *p*=0.454). A comparison between periods by pooled sex also showed no significant correlation with the number of grave-goods ($\delta^{13}CX^2$=0.664, *p*=0.718, $\delta^{15}NX^2$=1.558, *p*=0.459). A comparison between males from the three periods did not show any correlation between diet and status and the same was found for females (Males:$\delta^{13}CX^2$=0.209, p=901, $\delta^{15}NX^2$=3.892, *p*=0.143; Females: $\delta^{13}CX^2$=0.152, *p*=0.927, $\delta^{15}NX^2$=0.463, *p*=0.791).

Table 7.76. Comparison of carbon and nitrogen stable isotope values between periods at *Tepe Hissar* by number of grave-goods

Grave-goods no.	No.	Hissar I		No.	Hissar II		No.	Hissar III	
		$\delta^{13}C$‰	$\delta^{15}N$‰		$\delta^{13}C$‰	$\delta^{15}N$‰		$\delta^{13}C$‰	$\delta^{15}N$‰
0	0	-	-	1	-20.1	12.7	6	-19.7	11.5
(1-4)	5	-19.9	11.9	7	-19.5	11.8	32	-19.7	12.3
(5-9)	2	-19.5	11.4	2	-19.6	13.1	7	-19.3	12.5
(10-14)	1	-19.7	12.5	0	-	-	0	-	-
(15-19)	-	-	-	1	-18.9	12.5	1	-19.5	12.4
20+	-	-	-	-	-	-	2	-19.1	11.6

Figure 7.98 illustrates the relationship between the number of grave-goods and nitrogen values, respectively for males and females by period. Neither males nor females showed a particular pattern of correlation between the number of grave-goods and nitrogen isotope ratio within or between periods.

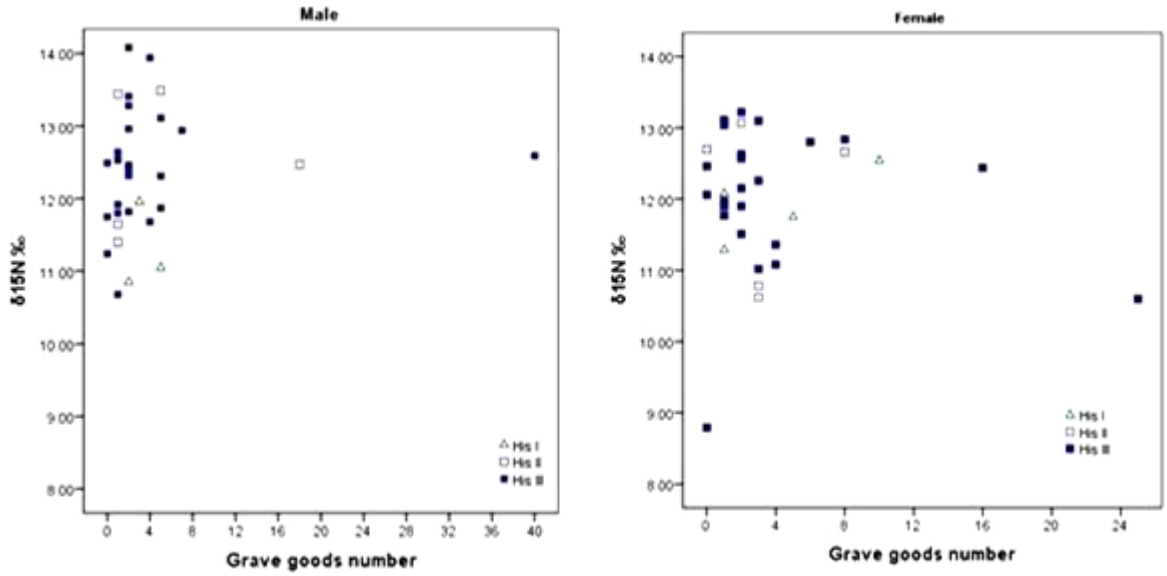


Fig 7.98. Nitrogen isotope ratios and social status, by period

This chapter has described the resulting data from the current research, and the next chapter discusses them.

Chapter 8 : DISCUSSION

This chapter discusses the data in the context of the research hypotheses and questions (see Chapter 1).

The human skeletal series from *Tepe Hissar* is a unique collection which spans the early to late occupation phases of this site. Analysis of it has provided not only a key test of the popular and conventional image of the Chalcolithic and Bronze Age there, but has also opened a new window on evidence that is central to gaining an understanding of the lives and social environment of the ancient populations from the Central Iranian Plateau during that time. *Tepe Hissar* was occupied by the end of the 5th millennium B.C. (see Chapter 2). However, remarkable cultural shifts, technological innovations and development, and economic growth at this site in the 4th millennium B.C. (Hissar II), again in the 3rd millennium B.C. (Hissar III), accompanied by site abandonment and reoccupation, and finally abandonment of the site around the early 2nd millennium B.C. (see the details described in Chapter 2), raise questions about whether these changes occurred as an indigenous development with total population continuity, or as a result of a diffusion of foreign cultures into the population or even population replacement. This study attempted to understand if the cultural changes in *Tepe Hissar* were accompanied by influxes of new people into the site, particularly in Hissar II and III, which ultimately impacted on the subsistence economy, diet, and general health of the population, and also resulted in a rise of tension and interpersonal violence.

8.1. Palaeodemography at *Tepe Hissar*

The demographic structure of archaeological populations is likely to be biased by different factors, such as poor preservation, type of burial, processing of skeletons, incompletely recovered samples that do not represent the original living population, curation, selective mortality and unknown fertility, migration, as well as inaccurate skeletal ageing and sexing techniques (see section 6.2.3- Henderson, 1987; Anthony, 1990; Wood et al., 1992; Waldron, 1994; Norman et al., 2005).

The excavated skeletal remains from *Tepe Hissar* do not represent the total remains from the site; they are a sample of the skeletons uncovered from different mounds and different periods. Many of the skeletal remains are unexcavated and it is not known whether the population buried for each period at this site is representative of the total population of that period. Of a total of 1637 human skeletons uncovered during excavations by Schmidt (1933, 1937), 397 (about 25%) of the skeletons from periods I,

II and III, and period IV (Islamic period) were transferred to the University of Pennsylvania and have been curated in the Penn Museum since then. Unfortunately, the rest of the skeletons may have been reburied or curated in an unknown place in Iran. However, it is not known whether Schmidt selected them randomly, by sex or age, or based his selection on the presence of disease, the place where he uncovered them (e.g., Main-Mounds, South-Hill), preservation/completeness, or perhaps period, or other unknown criteria. The majority were adult and mostly from Hissar III (n= 287), with 53 and 28 skeletons from Hissar II and Hissar I periods, respectively. Few skeletons belonged to non-adults or from the Islamic period, and some were from an unknown period. Overall, a high percentage (47%) were in a poor state of preservation, 44% were in a better condition and just 8% were in a good state of preservation. Preservation may thus have influenced the accuracy of the demographic profile of this site. Also, since each period contains sub-periods and covers a long span of time between ~ 500 to 1000 years, the combination of different generations or possibly new populations in each period must be taken into account as these are mortality samples, which are not the same as samples of a living population (Knüsel and Smith, 2014: Xlii).

The palaeodemographic data indicate differences in sex distribution for each period at *Tepe Hissar*. These differences were significant for Hissar II and III, but not Hissar I (see section 7.2). Comparison of mortality rates showed a different distribution for males and females for the age-categories for each period and these differences were significant for Hissar I and III, but not for Hissar II. In each period mortality was higher among females under 25 years old (YA1) than males from the same age-range. In other words, there were more young females between 18-25 years old in each period compared to males (Figure 8.1). Why should the percentage of deaths be higher in YA1 females in each period compared to males? In Hissar II the percentage of deaths for YA1 females was 32.3% compared to zero deaths for males, and it was also the highest compared to the female deaths at different ages in this period. The majority of Hissar III females died in the 18-35 year age-range and the highest mortality was estimated for YA2, but the percentage of deaths was again lower for males. Why was the percentage of deaths higher among both YA1 and YA2 females in Hissar III compared to the males from this period, and why was the % of deaths of YA2 females 50% more when compared to YA1 females?

The discrepancy between male and female mortality in the YA1 age-group may be explained by the fact that females younger than 25 years old can be affected more by

hazards than males in that age-range (e.g., the related hazards of pregnancy and childbirth in women- Buikstra and Beck, 2006:152; Souza et al., 2010). In the case of a lower % of YA1 male deaths in each period compared to YA1females, it is suggested that young males may have died before age 18 (e.g., childhood disease, conflict- see section 8.4), or perhaps migrated to elsewhere, or survived to an older age, or possibly that some females migrated from elsewhere into the site without their males (Anthony, 1990; Buvinić et al., 2013). There are sex differences in immune response to diseases and men show weaker and a less effective immune response to disease compared to women (Teriokhin et al., 2004; Møller et al., 2009). Metric analysis showed that there were few YA1 female who showed biological distance when compared with others in each period (see below). However, study of cranial trauma showed the presence of peri-mortem head injury among some YA1 females in each period (Hissar I:1/100%, II:1/25%, and III:2/12%), suggesting violence as one cause of death for these young females (see section 8.4). Interestingly, the peri-mortem trauma for Hissar II almost corresponds to the mortality data from this period and the differences between ages and sexes. In Hissar III young females (YA1,YA2) also showed a higher rate for peri-mortem cranial injury compared to the males from this period. Interestingly these data corresponds to the mortality rates for these age groups, suggesting that violent conflict may have been one of the causes for death of young females in Hissar III, and they were possibly twice as likely to be the victim of violence than young males. The "conflict literature" distinguish that young males typically suffer the highest mortality in conflicts/war, but 'when the conflict is on home territory, women may also suffer elevated mortality, and they do so particularly as an indirect consequence of war.' (Giles and Hyndman, 2004; Merry, 2011; Buvinić et al., 2013:8).

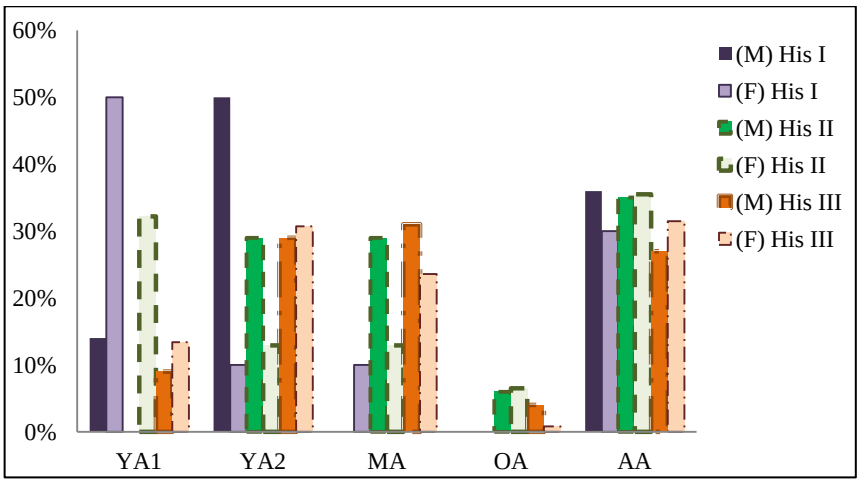


Fig 8.1. Age at death distribution for Tepe Hissar, by sex and age: M(male), F(female)

The percentage of males who died in the YA2 age-group was higher for both Hissar I and II compared to females of a similar age in these periods, but for Hissar III mortality increased among MA males compared to MA females. These differences suggest that YA2 males from Hissar I and II were more exposed to disease and stress (e.g., conflict: Giles and Hyndman, 2004; Merry, 2011; Buvinić et al., 2013) compared to YA2 females, or perhaps that there were fewer females who survived in that age-group. However, in Hissar III the percentage of mortality for the YA2 males was only 2.0% less than for females. Although more males than females died in the 36-50 year age group (MA) in Hissar III, assuming that males lived longer into older age (e.g., MA) than females in this period, or perhaps they may have experienced more stresses (e.g., conflict) than females from this age-group. These data correspond with the evidence for peri-mortem cranial trauma from this period (see section 8.4).

There were significant differences in the distribution of mortality among females. The mortality rate for YA1 females decreased steadily as time passed and the rate for Hissar III was the lowest for this age-group, although Hissar III females died more frequently in the 26-35 age-group (YA2) compared to females from Hissar I and II. Why was the mortality rate lower among YA1 females in Hissar III compared to previous periods but sharply increased among YA2 females from this period? YA1 females from Hissar III may have experienced better health and less stress compared to YA1 females from previous periods, and YA2 females from Hissar III. A decrease in the mortality rate for YA1 females in *Tepe Hissar* over time corresponds to the peri-mortem cranial trauma data, showing YA1 females from Hissar III were possibly less victims of violence compared to females from Hissar II and I.

Overall, a comparison between periods showed significant differences in mortality rates between Hissar I and II and III in all age-categories (Figure 8.2). The proportion of YA1 age-group was higher in Hissar II than other age-groups in this period, but in Hissar I and III there were more YA2 age-group. However, the percentage of YA1 was lower in Hissar III compared to the YA2 and MA age-groups in this period. Nevertheless, the proportion of YA1 was higher in Hissar II than other age groups in this period, but in Hissar I and III there were more individuals in YA2. However, the percentage of YA1 was lower in Hissar III compared to the YA2 and MA age groups in this period. Why should the number of YA1 be lower in Hissar III? What happen to them? It is suggested that some non-adults from Hissar III possibly experienced more childhood stress or conflict and did not survive to reach adulthood, or YA1 may have

migrated elsewhere. Why was the % of YA2 death higher compared to YA1 in Hissar III, and the percentage of females almost similar to males in the YA2 category? Is this due to an increase in the population among this age-group? The percentage of individuals that died in the MA age-category was higher for the Hissar III group than for previous periods. The metrical data (cranial and dental) showed that the majority of individuals from Hissar III who exhibited biological distance from others were YA2 and MA. On the other hand, cranial trauma from this period also showed a higher occurrence of peri- and ante-mortem injury among MA (males and females) compared to the other age-groups and males were more affected than females. This finding suggests a possible link between the biological distance data, mortality and violent cranial injury among this age-group from Hissar III. The increase in presence/or death among MA and YA2 individuals compared to YA1 in Hissar III, as well as the evidence of violence could be regarded as a possible population increase (mostly YA2 and MA) and a rise in conflict in this period; however, MA individuals may have experienced more interpersonal conflict than those younger than 35 years old (YA1, YA2).

The percentage of individuals who survived to over 50 years old was different between the periods and Hissar II had the highest proportion of old adults (males 6%, and females 6.5%) compared to Hissar III (males 4%, females 0.8%) and Hissar I (0%). Modern clinical studies show considerable variation in sex difference in longevity and mortality, indicating that men on average live at least five years less than females due to differences in their physiology, immune system and response to disease (Teriokhin et al., 2004; Møller et al., 2009; e.g., Iran- Pourmalek et al., 2009; United Nations, 2013). However, this was not the case at *Tepe Hissar*, since the percentage of males surviving to the older ages in Hissar II (except the rate for OA which was equal for both sexes) and Hissar III was higher compared to females. Some OA from Hissar II and III had evidence of peri-mortem head trauma.

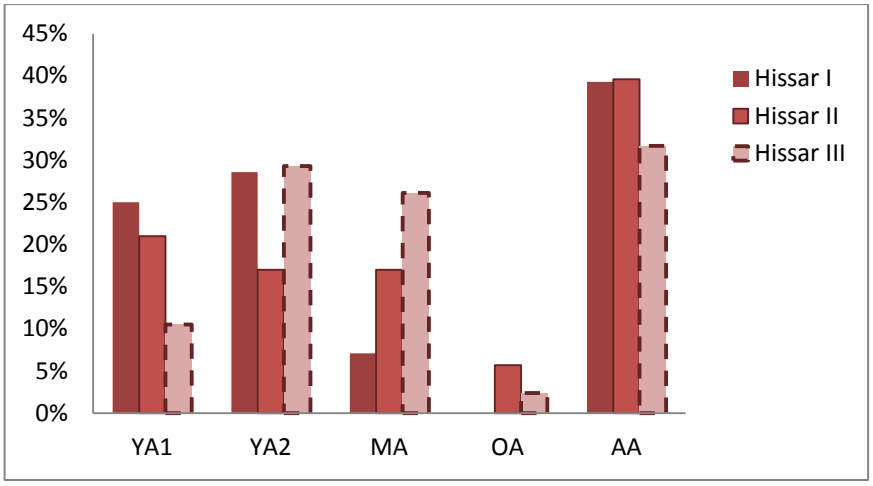


Fig 8.2. Adult mortality rates for the three periods at *Tepe Hisser*

8.2. Population Affinities: Normal Variation

8.2.1. Metrical Analysis

(i) Hissar I

The archaeological data from Hissar I indicate continuous cultural development (Schmidt, 1937:44) having contact with, and influence from, indigenous Central Iranian Plateau cultures (e.g., Sialk) which diminished at the end of this period (Fazeli pers. comm. 2013- see Chapter 2). Thus it was hypothesised that the inhabitants of Hissar I were a homogenous population and possessed close biological affinities with each other (Hypothesis 1). Mahalanobis distances showed that some individuals from Hissar I had close biological affinities, while some represented fewer similarities, and a few (male:1/9, female:2/6) showed larger distances when compared with others (see Chapter 7, Figures 7.23-24). The results of the PCA also did not show very close homogenous connections between individuals, and there were only two individuals, a male and a female, who displayed close affinity (see Chapter 7, Figure 7.29). This suggests that there is little connection between the evidence of archaeological continuity and the biological homogeneity in Hissar I; there were possibly other individuals/groups of people living close to the majority population of *Tepe Hissar* at that time. However, small sample size and poor preservation from this period must be considered. Due to this limitation, this data is only based on dental metrical analysis of this period.

(ii) Hissar II

In the early-half of the 4th millennium B.C. and at the end of Hissar I period, *Tepe Hissar* witnessed remarkable cultural transformations, suggesting the arrival of foreign invaders ("Grey-Ware" people) into the site at that time (see Chapter 2). A second

infiltration of new people has been suggested to have occurred in the middle part of Hissar II period, which finally caused the collapse of *Tepe Hissar* in the early third millennium B.C and the end the Hissar II period. Archaeological data suggests that during the settlement of Hissar II the site was in contact with, and influenced by, the Gorgan region of north-eastern Iran and Southern Turkmenistan (Helwing, 2006; Thornton, 2009). This study hypothesised that there were similarities and dissimilarities in biological affinities between individuals/groups of people from the Hissar II period, due to influxes of newcomers (Hypothesis 2a). The results obtained from Mahalanobis distances and PCA did not show that the Hissar II inhabitants were a very homogeneous population, but some individuals had greater similarity with each other, while some displayed less similarity (e.g., based on craniofacial measurements (PCA)- males:2/7, females:4/10- see Chapter 7,Figure 7.14) and a few were morphologically isolated (e.g., craniofacial measurements (PCA)- males:2/7, females:1/10- Figure7.14) (see Chapter 7,Figures 7.10-11; Figures 7.25-26,30). This could be regarded as possible evidence for population variation and/or demographic changes at *Tepe Hissar* during the 4th millennium B.C. This supports the above hypothesis (Hypothesis 2a) that during Hissar II period the site was occupied by different groups of people with possibly different genetic makeup, who represented similarity and dissimilarity in biological relationships with each other. However, the extent of cranial trauma may indicate that these population exchanges involved violence and interpersonal conflict (see section 8.4); this data correspond to the archaeological data from Hissar II (see Chapter 2). In an early study of the *Tepe Hissar* population based on "racial" comparison, Krogman (1940a) indicates the presence of two groups in Hissar II, Mediterranean and Proto-Nordic race. The non-metric traits data from Hissar II also showed different frequencies for each trait, as well as the appearance of new traits in this period which may indicate the presence of new individuals in this period (see section 8.2.2).

This study also hypothesised that there was no biological continuity between three periods at *Tepe Hissar*, due to the remarkable cultural-economic changes (Hypothesis 2b), suggesting each period was occupied by different groups of people. The biological distance comparisons based on the dental measurements demonstrated that affinities were not very close between Hissar II and Hissar I and, except for a few individuals, all males and females from Hissar II revealed differences when compared to Hissar I males and females, respectively. This finding provides some support for the hypothesis of the arrival of new, biologically different people in Hissar II. On the other hand, close

affinities between a few individuals from Hissar I and II may also indicate some biological continuity at this site. This finding corresponds with the results from the non-metric study from these periods (see section 8.2.2), as well as archaeological data (see Chapter 2). Thus cultural changes in *Tepe Hissar* during 4th millennium B.C. may have been accompanied by biological exchange and influx of new and genetically distinct individuals. However, there were also traces of biological continuity from Hissar I, suggesting that Hissar I may have not been abandoned with biological continuity to Hissar II as well as to Hissar III.

The PCA of mean dental measurements for males and females separately showed a lack of biological similarity between males and females from Hissar II and Hissar I, respectively (see Figure 7.33). However, the data from Hissar I are just based on dental metrical analysis and the cranial data are very few for comparative purposes, but these data still help to understand the Hissar I population affinities with other periods at *Tepe Hissar*.

(iii) Hissar III

The archaeological data showed major cultural changes in the early third millennium B.C. and the site entered a new era, Hissar III. This transition from Hissar II to Hissar III was suggested to be due to dynamic force or foreign influence (Schmidt, 1933). The archaeological evidence shows remarkable cultural changes and violence and finally collapse of Hissar III, suggesting hostile invasion possibly from the east, contemporaneous with events occurring in the Gorgan plain. During Hissar III, *Tepe Hissar* was in contact with, and influenced by, north-eastern Iran and southern Turkmenistan (Helwing, 2006; Thornton, 2009- see Chapter 2). It is assumed that these cultural changes were also accompanied by "biological exchange". This study hypothesised that there were similarities and dissimilarities in biological affinities between individuals/groups of people from the Hissar III period (Hypothesis 2a). The results of multivariate statistical analysis supported the above hypothesis that Hissar III inhabitants were not a strongly homogeneous population. Mahalanobis distances analysis of cranial and dental measurements for males (see Chapter 7, Figure 7.12, 27) and females (Figure 7.13, 28), separately, revealed similarities as well as dissimilarities within the population from this period. However, some people displayed large biological distances from the rest of the population (e.g., craniofacial measurements- males:1/67, females:4/47- see Figure 7.12-13). These data could be regarded as possible

evidence of population variation during the Hissar III period, which may have been associated with new comers with a different genetic makeup. These data are consistent with the archaeological data (e.g., an immense range of variation of burial practice, pottery, and other artefacts- see Chapter 2).

PCA also showed similar data (Figures 7.15,31) and some males displayed a close connection, while some exhibited less similarity, and some were very morphologically isolated (see below). In the case of females, small groups showed close similarities, while some represented less affinity, and a few did not show any connection with the rest (e.g., craniofacial measurements (PCA)- males:7/67, females:17/47- see Figure 7.15). Some males and females in this period also showed close biological affinities to each other. Krogman (1941a:36), in his racial study of the Hissar III population, found several cranial "types" in Hissar III and stated that Mediterranean and Proto-Nordics were in the majority, while other "types", including Negroid, Alpine, Armenoid, and Mongoloid were in minority. The first two "types" were presented in Hissar I and II as well, but the others from Hissar III only.

However, PCA of craniofacial and dental measurements between periods showed a pattern of biological similarity as well as dissimilarity between individuals from Hissar II and III (Figure 7.16-17 and Figure 7.32-33). This is interpreted as biological continuity between the periods, but there were also individuals/groups of people in these periods who did not represent any biological affinity with each other (e.g, craniofacial measurements- males:7/74, females:9/58- see Figure 7.16-17). This suggests that the cultural shift in Hissar III, was not accompanied by "total" biological replacement, but data showed biological homogeneity in some individuals from this period and in Hissar II. It is interesting that some Hissar III individuals displayed great homogeneity with some individuals from Hissar I. This may indicate a biological continuity from the early occupation to the end of the settlement. Overall, these data partly reject and partly support the hypothesis (Hypothesis 2b) that there was no biological continuity between the three periods at *Tepe Hissar*, consistent with the non-metric data (see below).

The PCA of mean craniofacial and dental measurements indicates a large biological distance between males from Hissar III and II, while females exhibited less distance, but were still not very close to each other (see Chapter 7, Figure 7.18, 7.34). Interestingly, the males from Hissar III showed closer similarity to males from Hissar I than Hissar II. But Hissar I females showed less similarity with Hissar III and II females. However, inequality in sample size may have affected this result.

Previous biological distance studies (Hemphill, 1998; Afshar, 2006) between regions, have suggested phenetic affinities between the inhabitants of Hissar III and the late Bronze Age inhabitants of Northern Bactria (Central-Asia) (2200-1500 B.C.), as well as with the middle Bronze Age (2500-2200 B.C.) populations of Southern Turkmenistan, e.g., Altyn Tepe. This suggests gene flow between these regions (Hemphill, 1999a). Barton and Hemphill (2011) also suggest contact between populations from the Iranian-Plateau (Hissar III) and Central-Asia likely occurred in the early Bronze Age, but then ceased. In previous studies Hissar III individuals have also shown affinities with inhabitants from Shahr-i Sokhta in South-eastern Iran (3000-2200 B.C.- Hemphill, 1998, 1999a), and with people from Hassanlu IV (1250-750 B.C.- Hemphill, 2011) and Deilaman (1000-500 B.C.- Afshar, 2006) located in north-western Iran, and South-west of the Caspian-Sea, respectively. In these studies, however, inhabitants from Hissar II did not show close affinities with Central-Asian people, populations from Southern Turkmenistan, or other Iranian groups (except Hissar III).

(iv)Stature: Hissar I, II and III

Stature of the adults from *Tepe Hissar* was estimated to assess the pattern of population similarity/dissimilarity, and also the impact of socio-cultural and economic changes on nutrition, health, and on attained height of individuals from each period.

Differences in stature were found between male groups as well as female groups in each period, suggesting probable differences in genetic makeup, particularly for Hissar II and III, but they may also reflect differences in nutritional status, health, and impoverished living conditions experience by individuals during their childhood (Lettre, 2009, 2011). The results showed that Hissar II and III males were, on average, 13cm and 12.4cm taller than females, respectively (significant). However, the mean heights for both sexes for Hissar I were similar (insignificant). Since puberty occurs two years later in males, growth velocity is greater and continues longer in males compare to females (Seeman, 2000:7); these additional years of growth results in males growing taller, but puberty results in "recession" of growth. A delay in puberty also may result in continued long bone growth (ibid, 2000:7).

Comparison of the mean stature of males showed that mean height increased in Hissar II and III compared to Hissar I. Hissar II males were 3.7cm taller than those in Hissar I, and Hissar III males were 0.7cm taller than those in Hissar II (insignificant). This finding rejects the hypothesis (Hypothesis 3) that socio-cultural-economic changes

in Hissar II and III impacted on the general health of this population. It is suggested that any disruptions that did occur were not a problem for males, and they possibly experienced similar health/childhood illness across periods. However, indicators of childhood stress (e.g., CO) do not support this suggestion and show that cultural shifts had a considerable impact on general health of children (particularly boys). Hissar II boys experienced the highest level of childhood illness but this was less so for Hissar III boys. Adequate nutrition may have helped boys with ill-health or nutritional problems during Hissar II and III to recover from stressors, via "catch-up" growth (Steckel, 1995:1911), and attain their genetic height potential. The mean height for Hissar I (167.3cm) males was approximately consistent with those males found in the late Bronze Age from eastern Mediterranean sites (166.8cm- Angel, 1984); but the mean stature for Hissar II and III males was roughly closer to the Bronze Age males from *Shah Tepe* III (170.4cm- 3000 B.C.) in the south eastern Caspian Sea-Iran (Fürst, 1939).

The percentage of males with short stature (151-160 cm) was lower in the three periods compared to other stature ranges, and this percentage declined over time with Hissar III having 2.3% of males in this range (Figure 8.3). The majority of males were between 161-170cm and 171-180cm, but a small percentage from Hissar II and III were taller than 180cm (insignificant). However, a wide distribution of male statures for each period suggests significant variation in health, or different levels of childhood stress and growth disturbances, although genetic differences may also have played a role. The later suggestion corresponds to the metric and non-metric data. The metric data showed that among males who displayed biological distance with other males in both Hissar II and III, there were some between 175-189cm, supporting the assumption of immigration; however, the rest of these males were taller than 165cm. Comparison of the mean heights of the other Bronze Age males from Iran: Shahr-i Sokhta (2900-2000 B.C.) and Dinkha IV (1900-1600 B.C.), and males from Iraq: Kish (2900-2000 B.C.- 175cm, 181cm, and 180cm, respectively- Rathbun, 1984) showed that males from *Tepe Hissar* were shorter.

Comparison of mean statures of females from the three periods showed a decline in height through time, and females from Hissar I (166.8cm) were taller than Hissar II and III (158.5 and 159.3cm, respectively- insignificant). Nevertheless, comparison of female mean stature distribution from the three periods (Figure 8.3) showed that the percentage of shorter females (140-150cm and 151-160cm) increased in Hissar II, but proportion of females between 161-170cm decreased. However, females from Hissar III

showed a wider range of stature compared to Hissar II with more of shorter stature, already seen in Hissar II. A small percentage of females in Hissar III were between 140 and 150cm and one was shorter than 140cm. The stature reduction might have been due to a decline in health and poor nutrition among girls from Hissar II and III compared to Hissar I. This supports the hypothesis that cultural changes in Hissar II and III impacted on health and nutrition. The differences in the distribution of stature between females in each period, particularly Hissar II and III, suggest considerable variation between females in diet and quality of living conditions during their childhood growth, but may also indicate variation in genetic makeup (and population replacement) at the site. Nevertheless, the data on CO and DEH did not support the suggestion above. However, these differences in stature distribution correspond to the metrical and non-metrical data. Females who displayed biological distance from other females in Hissar II and III were between 147 and 165cm, supporting the assumption of a possible influx of new women with short stature from elsewhere. Hissar I females were 3.8cm taller than females (163cm) from Hasanlu (VII-IX- 5000-3000 B.C.- Iran), but the mean stature for Hissar II and III females was close to the stature of Bronze Age females from Shahr-i Sokhta (159cm- Iran) and Kish (159cm- Iraq- Rathbun, 1984).

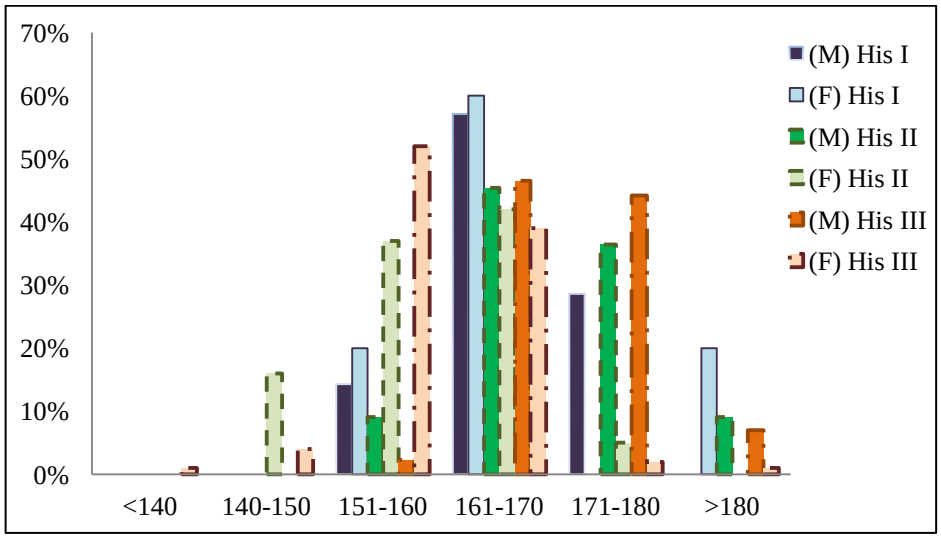


Fig 8.3. Adult stature distribution at *Tepe Hissar*, by sex and period(cm):M/male, F/female

8.2.2. Non-Metric Analysis

Classification trees constructed from "phenotypic" data have been shown to be correlated with "genotypic" data and to provide an alternative to "genetic markers" (Ricaut et al., 2010; Movsesian, 2013- see Chapter 3). It was hoped that the large number of traits used would provide insight into biological relationships. Post-cranial

non-metric traits are believed to have more of a mechanically and occupationally induced aetiology (Capasso et al., 1999), but the analysis of cranial, post-cranial, and dental non-metric trait frequencies showed that they correspond to each other with similar patterns between and within periods, particularly for Hissar II and III, suggesting that cultural changes and events were accompanied by the arrival of new individuals with a different morphological background (see above).

(i) Hissar I

The result for skeletal and dental non-metric traits frequency was not consistent among all individuals from this period. Some traits were frequent, others less frequent and some were absent in Hissar I, but present in later periods (see Table 7.31-33). The frequency of traits expression did not differ significantly between females and males in this period. The high frequencies of similar traits (particularly cranial and dental traits) show a pattern of dominant inheritance (Scott and Turner, 1997:139; Stojanowski and Schillaci, 2006) and possibly biological linkage between individuals who carry those traits, while traits with lower frequency represent more recessive inheritance and possibly indicate different individuals with a different biological background. However, the small sample size from Hissar I makes it difficult to see patterns of biological relationship between individuals in this period.

(ii) Hissar II

The data showed that the frequency of skeletal and dental traits was not consistent across all individuals from Hissar II, suggesting biological differences between the people. The presence of similar traits with a high frequency (see Chapter 7, Tables 7.31-33) suggests close biological similarities between some individuals/groups of people from this period (Scott and Turner, 1997:139), while the evidence of some traits with a lower frequency may imply an influx of individuals with different biological backgrounds (Stojanowski and Schillaci, 2006). This corresponds to the metrical data from Hissar II and could support the hypothesis of biological diversity in Hissar II (Hypothesis 2a). Comparison of trait expression between Hissar II and I showed continuity in occurrence of some traits into Hissar II, but some traits "disappeared" in Hissar II, while more new traits were introduced in this period (see Tables 7.31-33). This is similar to metrical data with evidence of biological continuity between Hissar I and II as well as new individuals in Hissar II. As with metric analyses, this result (based on male samples) rejects the hypothesis that Hissar II people differed biologically from

the people of Hissar I (Hypothesis 2b). Females could not be investigated as the sample size from Hissar I was one.

(iii) Hissar III

The non-metric traits analysis showed inconsistency in the frequency of traits across all individuals from Hissar III (see Tables 7.31-33), suggesting biological diversity in this period. This corresponds to the metrical data and supports the hypothesis of the presence of divergent individuals and/or population in this period (Hypothesis 2a).

There was continuity in occurrence of some similar traits from Hissar II to III, however, some new traits with lower frequency first appeared in Hissar III (Figures 7.42,7.47, and7.53). A few traits presented in Hissar II females, but not in Hissar III. Again this corresponds to the metrical data, showing continuity in biological affinity between Hissar II and III, with influx of some dissimilar individuals. As with the metric data, this rejects the hypothesis (Hypothesis 2b) that people from Hissar III were totally different from Hissar II. The non-metric data indicate continuity in occurrence of some similar traits over the three periods. A few traits from Hissar I "disappeared" in Hissar II, but "occurred" in Hissar III, suggesting biological similarity between Hissar III individuals and Hissar I, and again this corresponds to the metrical data, but does not support Hypothesis 2b (see Chapter 1).

8.3. Stress and Disease: Abnormal Variation

The study of stress indicators and pathological conditions in archaeological populations is an important tool to understand the different aspects of life in ancient human societies (Ribot and Roberts, 1996; Brickley and Ives, 2008:7). However, these studies are likely to be biased by poor/ambiguous definition of pathological changes, problems with the interpretation of these lesions, limited range of recording techniques, poor preservation and missing bones/teeth, and sampling bias (Wood et al., 1992; Lewis and Roberts, 1997). On the other hand, skeletal remains are inherently biased and tend to record only a limited subset of the stresses to which the body is exposed, for example chronic conditions which persist long enough in the body to lead to changes on the bones or teeth (Cohen, 1989:120; Wood et al., 1992). Thus, the lack of pathological changes in a skeleton does not mean that the person has not experienced disease during life, but he/she may have been afflicted by the same disease or deprivation but, because of low resistance, died before any bony response could develop (Wood et al., 1992;

Pinhasi and Bourbou, 2008). Therefore, it is impossible to distinguish the difference between healthy individuals with no skeletal lesions, and those who died before disease left any marks on the skeleton. Moreover, genetic variations (e.g., susceptibility and resistance to infectious disease), for example, among humans may affect the frequency of disease from group to group (Pinhasi and Bourbou, 2008). Nevertheless, these biases may influence reconstructing population prevalences of pathological conditions from skeletal lesion frequencies (Wood et al., 1992), and consequently effect on the reliability of interpretation of health and disease in that population.

It was hypothesised that socio-cultural-economic transitions at *Tepe Hissar*, particularly in Hissar II and III, impacted on the subsistence economy, the diet people ate, and their general health, and that this also differed between males and females.

8.3.1. Stress and Metabolic Bone Disease Indicators

Examination of markers of stress (cribra orbitalia, porotic hyperostosis of skull vault, and dental enamel hypoplasia) and metabolic bone diseases (vitamin C and D deficiencies, and osteopenia/osteoporosis) has provided some information about "health status" and "stress" from different periods of occupation. The results showed people in each period experienced different episodes of illness and stress. A comparison between the three periods showed a slight decline in health (based on the rate of CO and PH-see below) and a slight increase in metabolic bone disease over time. Since these changes were minor, they could not support the hypothesis (Hypothesis 3) that socio-cultural-economic changes taking place at this site, particularly in Hissar II and III, had a detrimental effect on health and nutritional status of people from these periods.

(i) Cribra orbitalia (CO)

The presence of CO in each period at *Tepe Hissar* suggests the attempts of individuals to adapt to adverse environmental conditions and stressors (Stuart-Macadam, 1992:45), affecting both sexes equally from different age-groups. This lesion is indicative of iron deficiency anemia as a result of nutritional stress, chronic blood loss, infection or exposure to pathogen, with infection and pathogen exposure (e.g., fungi, viruses, bacteria, and parasites) more often involved than nutrition (see Chapter 4). Comparison between males showed a significant difference in the prevalence rates for CO between the periods and Hissar II showed the highest rate compared to Hissar I and III (Tables 8.1 and 7.57). These data suggest that boys from Hissar II were

significantly exposed to childhood stress/illness and pathogens (e.g., parasites: Stuart-Macadam,1992; Armelagos, 1998; Walker et al., 2009) compared to Hissar I, supporting the hypothesis that changes during Hissar II impacted the health of people (Hypothesis 3). However, boys may have experienced more frequent episodes of stress or recovered from several illnesses during life compared to girls. However, Hissar III males experienced less childhood stress compared to Hissar II, suggesting the introduction of fewer stressors or new pathogen compared to Hissar II. Interestingly, these data correspond to the demographic profile from Hissar II (see above), suggesting that the lower percentage of males in this period compared to females, particularly YA1 males (0%) compared to YA1 females (32.2%) may have been due to frequent childhood disease among boys and they may not have survived into adulthood.

There were no significant differences in the prevalence of CO between females at this site, so females from three periods may have experienced similar rate of stress during childhood and the events occurred in Hissar II and III did not affect woman significantly. However, a high rate of CO suggests females as males attempted to adapt to severe environmental stress. The stature measurements for females support this suggestion. The presence of more shorter statured females in Hissar II and III suggests females were more affected severely by childhood illness and stress and could not "catch-up" growth, but this was more pronounced for Hissar II and III females, suggesting association with the cultural changes in these periods.

Studies showed that the prevalence rate for iron-deficiency anaemia in modern Iranian population is between 20% and 39% (Fathi-Najafi et al., 2013); however, the rate for genetic anemias, for example, thalassemia is between 4% and 10%, and the higher prevalence is around the Caspean Sea and Persian Gulf (10%), but it is between 4% and 8% for other areas in Iran (Habibzadeh et al., 1998).

Table 8.1. Cribra orbitalia prevalence rates at *Tepe Hissar*

Period	**Male**	**Female**	**Indeterminate**	**Total**	
	%	*%*	*%*	*%*	*n*
Hissar I	20%	100%	-	33%	6
Hissar II	100%	64%	-	78%	18
Hissar III	49%	63%	-	55%	120

(ii)Porotic hyperostosis (PH)

The majority of cranial vaults examined in this study exhibited a slight to medium (scattered fine or large isolated foramina that had become a trabecular structure) degree of expression on parietal, frontal and occipital bones (Stuart-Macadam, 1985, 1991). PH

of cranial vault like CO is a marker of childhood stress, however, anemia (Resnick, 1995), inflammatory processes of the skull, hematoma and chronic scalp infections (Grauer, 1993; Schultz, 2001), and pathogen/intestinal parasites (e.g., hookworm infestation- Holland and O'Brien, 1997) are suggested as the possible cause of this condition (see Chapter 4). The occurrence of PH in each period could be an indicator of these conditions. There was no significant difference in the frequency of this condition between periods, suggesting that *Tepe Hissar* people possibly have experienced similar rate of health/stress over time. These data did not support the hypothesis of an association between cultural changes and an increase in stress over time (Hypothesis 3).

Table 8.2. Porotic hyperostosis prevalence rates at *Tepe Hissar*

Period	Male	Female	Indeterminate	Total	
	%	*%*	*%*	*%*	*n*
Hissar I	80%	0%	-	67%	6
Hissar II	86%	82%	-	83%	18
Hissar III	92%	84%	-	88%	120

(iii)Dental enamel hypoplasia (DEH)

DEH was common at *Tepe Hissar*, and approximately three-quarters of individuals were affected in each period (Table 8.3, Figure 8.4). In each period males and females from different age-categories experienced DEH equally. These data corresponds to other indicators of stress (PH and CO). The rate for DEH is similar to the 77% reported from Bronze and Iron Age *Dinkha Tepe* from Iran (Rathbun, 1984).

Table 8.3. DEH prevalence rates at *Tepe Hisser*

	Male		Female		Indeterminate		Total			
Period	Individuals	Teeth	Individuals	Teeth	Individuals	Teeth	Individuals		Teeth	
	%		*%*		*%*		*%*	*n*	*%*	*n*
Hissar I	67%	77%	75%	72.70%	100%	100%	72%	18	77%	106
Hissar II	57%	70%	83%	88%	0%	0%	70%	20	75.50%	106
Hissar III	76%	87%	77%	77%	60%	65%	76%	128	81%	591

The high frequency of DEH in each period likely reflects several episodes of nutritional stress (e.g., vitamin D deficiency), childhood illness, fever, infection, or other environmental factors may have affected the first 10 to 11 years of boys' and girls' lives (Lewis and Roberts, 1997; Ogden, 2008; Masumo et al., 2013; Salanitri and Seow, 2013; Memarpour et al., 2014). For example, Gisoo and Mohseni (2010) examined the prevalence of DEH in the first permanent molar teeth among 1637, 6-7 years old children from Iran; 7.5% of them showed DEH; they found an association between the present of DEH and the maternal and childhood disease.

Nevertheless, the slight differences observed between the sexes in each period suggest that girls and boys experienced similar rates of these stressors. A comparison between periods at *Tepe Hissar* showed a minor difference in the frequency of DEH over time (reject the Hypothesis 3), indicating that cultural changes and events at *Tepe Hissar*, did not significantly impact on the health status of people. Overall, these data again suggest that the *Tepe Hissar* population (both sexes from different age ranges) had similar levels of health and nutrition over time.

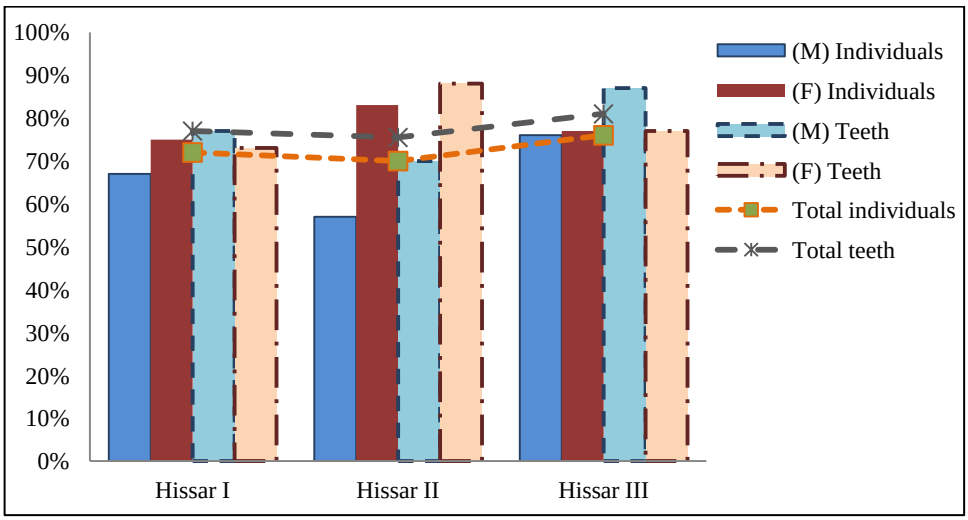


Fig 8.4. DEH prevalence rates at *Tepe Hissar*, by sex and period:M/male, F/female

(iv)Vitamin C deficiency- scurvy

The vitamin C deficiency data showed none of the individuals from Hissar I and Hissar II were affected by scurvy, but there were two (1%- 2/251) MA individuals (one male, one female) from Hissar III had possible bone changes of vitamin C deficiency, and there were no significant differences by sex, age or period. This suggests the population always had access to food resources that are rich in vitamin C (e.g., fresh vegetables, fruits, milk, meat and fish- WHO, 1999; Ortner, 2003:384) in terms of their nutritional requirements or appropriate food preparation techniques to preserve vitamin C in foods. This supports the isotopic results (see below), indicating consumption of animal protein (e.g., meat, milk) and possibly fish. This result rejects the Hypothesis 3. However, limitations such as poor preservation, ambiguous/limited definition of osseous manifestations of scurvy in adults, and a limited range of diagnostic criteria are factors to consider. Many pathological changes of scurvy are similar to other metabolic disorders such as anemia, rickets, and osteoporosis, as well as with traumatic or inflammatory conditions (Brickley and Ives, 2008; Geber and Murphy, 2012-see Chapter 4). These biases, likely limited effective diagnosis in this study,

underestimating the prevalence rate of scurvy. Short periods of vitamin C deficiency also only affect soft tissues; by introducing vitamin C into the diet most physical signs can be resolved within one or two weeks (Pimentel, 2003). Therefore, it is thought that there may have been more people who had been temporarily deprived of vitamin C, but then provided with it, or died before any osseous changes had manifested. On the other hand, the manifestation of scurvy is fairly minor and non-specific in adult skeletons compared to non-adults (Brickley, 2000:186).

(v)Vitamin D deficiency

An insignificant increase in prevalence rates for total vitamin D deficiency (residual rickets/osteomalacia, and osteopenia/osteoporosis) was found through time, from 48% in Hissar I, through 61% in Hissar II to 67% in Hissar III (see Table 8.4). The prevalence rates indicate that almost half of the individuals from each period had insufficient access to vitamin D (e.g., exposure to UV light, or sufficient in food) and this rate was similar for both sexes in each period. This does not support the hypothesis (Hypothesis 3) that cultural changes and events that occurred at *Tepe Hissar*, particularly in Hissar II and III, impacted on their subsistence economy, the diet people ate, and their general health. This does, however, indicate that *Tepe Hissar* population had similar levels of food resources and living condition over time.

Medical studies of vitamin D deficiency among modern Iranian population showed a high prevalence rate for both sexes (Hashemipour et al., 2004; Heshmat et al., 2008). For example, Heshmat et al. (2008) examined 5232 healthy men and women (between 20 and 69 years old) from five big cities in Iran: Tehran, Tabriz, Mashhad, Shiraz and Booshehr. The result of their research showed that almost half of the individuals (both sex groups) experienced moderate to severe vitamin D deficiency. In another study in Iran the rate was 72% for men and 75% for women (Moradzadeh et al., 2008). It is suggested that unsuitable dietary habits, air-pollution (particularly in Tehran and Mashhad), and clothing habits, especially among women as important factors for the high prevalence of vitamin D deficiency in Iran (Heshmat et al., 2008).

Table 8.4. Vitamin D deficiency prevalence rates at *Tepe Hisser*

Period	**Male**	**Female**	**Indeterminate**	**Total**	
	%	*%*	*%*	*%*	*n*
Hissar I	43%	60%	33%	48%	15
Hissar II	69%	60%	33%	61%	36
Hissar III	68%	68%	67%	67%	217

(a)Residual rickets or osteomalacia

The prevalence rate for residual rickets or osteomalacia was slightly higher for Hissar II (50%) compared to Hissar I (43%), but in Hissar III decreased to 39%. However, these differences were insignificant, and both males and females from different age categories possibly were affected equally. This result rejects the Hypothesis 3. The high prevalence of residual rickets or osteomalacia in each period could indicate that some individuals/groups of people had less "access" to vitamin D resources (e.g., sunlight) and calcium for a prolonged time during childhood growth or even in adulthood (osteomalacia) (Kitanaka and Kato, 2000; Holick, 2006). For example, a clinical study of rickets and osteomalacia among 797 (795 female, 2 male- between 8 and 74 years old) modern individuals in the north-east of Iran, Mashhad, showed that all individuals were affected (Jokar et al., 2008); suggesting that clothing and inadequate sun-exposure as the most common cause for these conditions, particularly for women in Iran (Kazemi et al., 2009; Taheri et al., 2014- see above). Nevertheless, living and working conditions also could have put some individuals at risk for developing vitamin D deficiency. For example, some individuals may have spent most of the day working inside industrial workshops (e.g., metallurgy, making pottery) particularly in Hissar II and III, and were not exposed to sunlight.

The occurrence of vitamin D deficiency could have been due to exposure to toxic elements such as "lead" and "arsenic" which were widely utilized in metallurgical activities (particularly in Hissar II and III - Tosi, 1989). Thornton (2009) found that lead and arsenic were present in metal objects rising from <1Wt% Pb and <3Wt% As in Hissar I to >5Wt% Pb and <6.1Wt% As in Hissar II and peaking in Hissar IIIB-C at 16.1Wt% Pb, 1-5Wt% As. These elements are released during the smelting process or in metal cores or in coal-burning, and produce "stack dust" and "flue gas", contaminating the environment (Roy and Saha, 2002; WHO, 2010). Lead exposure can also occur through food (e.g., dairy products, meat, fish, grain, and cereal), air, water, and soil contamination, and the concentration of lead found can be between $7.6x10^5$ $\mu g/m^3$ in urban areas (e.g., residential areas near workshops) to more than $10\mu g/m^3$ in the vicinity of industrial sources and near smelters (Dart et al., 2004:1423; WHO, 2010). These toxic elements may have increased environmental pollution and affected both workshop and habitation areas at *Tepe Hissar*, thus affecting people's health. The distribution of metallurgical artfacts at this site suggests that metal production was wide spread activity among occupied areas of the site (Pigott, 1989:32). Lead interferes with

vitamin D synthesis and calcium function and interrupts bone and tooth maturation. It also inhibits haemoglobin production and may cause anemia (Stellman, 1998:23.21; Dart et al., 2004:1426-8; WHO, 2010; Yu et al., 2011). Arsenic affects overall general health and causes bone marrow suppression, bleeding, anemia, leukopenia, protein wasting, and cancer (Stellman, 1998:23.05; Abernathy, 2001; Fowler et al., 2007:389). So lead and arsenic may also have contributed to the occurrence of vitamin D deficiency, PH, and CO at *Tepe Hissar* (see above). Ostrander (2013) analysed the Coach Lane assemblage (1711-1857 A.D.) of North Shields, UK. He found correlations between lead poisoning and rickets, and scurvy; but no direct correlation was found between lead pollution and CO (see Millard et al., 2014) and reductions in average stature. Analysis of bone, tooth enamel, and tissue also are used in bioarchaeological research to determine lead pollution/poisoning in ancient populations (see Budd et al., 1998, 2004).

(b) Osteopenia or osteoporosis

The prevalence rate for osteopenia/osteoporosis increased gradually through time at *Tepe Hissar*. However, these differences were insignificant and reject the hypothesis (Hypothesis 3) that cultural changes had a significant impact on osteopenia/osteoporosis in people, particularly those from Hissar II and III periods. Osteoporosis is a condition correlated with increasing age, however, severe and prolonged inadequate dietary calcium and vitamin D, insufficient *sunlight* exposure, inefficiency in intestinal mineral absorption, intestinal parasites, parathyroid hormone secretion, and genetics are also accepted as aetiological factors (see Chapter 4). Low protein diet, malnutrition and under-nutrition are also important determinant of peak bone mass and therefore of the risk of osteoporosis (WHO, 2003). The results of current isotopic analysis (C/N) show sufficient diet for each period, suggesting longterm lack of exposure to UV light, air-pollution (e.g., lead, arsenic- see above), or pathological factors may have been the cause of bone-loss among *Tepe Hissar* populations, being more pronounced in Hissar III.

The data show a remarkable correlation, as expected, between ageing and prevalence of osteopenia/osteoporosis for Hissar III individuals, but evidence of osteopenia/osteoporosis was also observed among young adults (YA1 and YA2, 18-35 years) from this period and almost quarter were affected by this condition. In Hissar I and II all age groups were almost equally affected. Other bioarchaeological studies have

reported age-related bone-loss among past populations (e.g., Mays et al., 2006b). Nevertheless, the occurrence of osteopenia/osteoporosis among young adults (Figure 8.5) could be an indicator of prolong nutritional stress and vitamin D deficiency during childhood or early adulthood, or it could be an indicator of factors which inhibit vitamin D absorption (see above). However, lead and arsenic pollution may also have played a part (see above). The data suggest that many young adults (except YA2 from Hissar I and YA1 from Hissar II) experienced severe ill-health and malnutrition during childhood or early adulthood, or they may have worked in workshops (e.g., metal smelting) with "less" exposure to daylight and more contact with pollution.

The percentage of females who suffered osteopenia or osteoporosis were not significantly different to males in all periods, even though clinical studies indicate that females lose more bone than males due to differences in hormonal function (Seeman, 2000:14). The prevalence rates for vitamin D deficiency, osteopenia/osteoporosis, and CO between the sexes in different periods, were minor, and could not support the hypothesis (Hypothesis 3) that the events that occurred at *Tepe Hissar* impacted on health and nutrition of males and females in each period differently.

A clinical analysis of the prevalence rate for osteopenia and osteoporosis among 34,814 (between 30-69 years old) Iranian population (4886 men (mean age:49.2 years), and 29,928 women (mean age:52.5 years)) showed: 17% and 35% of the population age >30 years experienced osteoporosis and osteopenia, respectively (Irani et al., 2013). The rate for osteopenia (premenopoausal:21%, postmenopausal:40%) and osteoporosis (premenopoausal:3%, postmenopausal:19%) was higher among women than men (33%, 12%, respectively) (ibid).

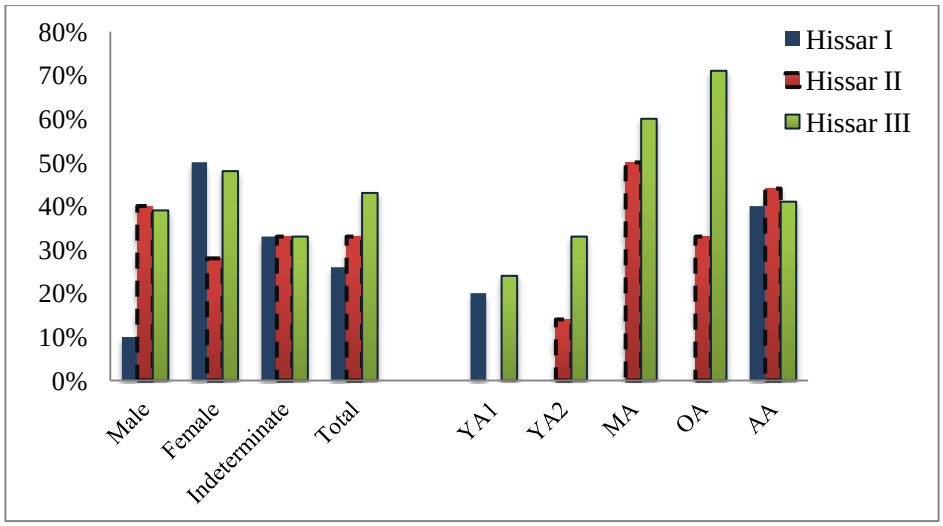


Fig 8.5. Osteopenia or osteoporosis prevalence rates at *Tepe Hissar*, by sex and age

Overall, the archaeological data indicate that parallel to significant cultural shifts and influxes of new people at *Tepe Hissar,* there was development in technology, an increase in industrial activities, craft specialisation, and accompanying manufacturing workshops, and increasing social complexity (Schmidt, 1937; Tosi, 1989, Tosi and Bulgarelli, 1989), which would have been accompanied by many individuals working in those industries with a division of labor, particularly during Hissar II and Hissar III (4^{th} and 3^{rd} millennium B.C). This study has found evidence of a minor increase in biological stress demonstrated in CO, but no change in metabolic bone disease (vitamin C, D deficiency and osteopenia or osteoporosis) in Hissar II and III, compared to Hissar I. The data indicate that changes that occurred at *Tepe Hissar*, particularly during the 4^{th} to the early 2^{nd} millennium B.C. (Hissar II and III), did not significantly impact on health and nutritional status of this population (reject the Hypothesis 3). It appears that the society of *Tepe Hissar* experienced similar health/stress and nutritional status during Chalcolithic and Bronze Age, and both sexes were affected equally in each period.

8.3.2. Dental Disease

Oral-health is strongly related to diet and nutrition (Petersen, 2003), and '[d]isease of the teeth reflects much of what is in the diet' (Eshed et al., 2006:146). Examination of dental pathology in conjunction with dental attrition, and DEH has significant implications for a better understanding of oral-health, diet, food preparation techniques, and nutritional stress in ancient populations, particularly in societies undergoing cultural changes and subsistence transitions (King and Norr, 2006:245; Chamberlain, 2006:162- see Chapter 4). The subsequent sections discuss the evidence for oral-health, subsistence and diet in the dentitions of people at *Tepe Hissar*.

Overall, the data demonstrated that oral-health was not consistent among the Chalcolithic and Bronze Age inhabitants of *Tepe Hissar*. People from Hissar I showed better oral-health and appeared to have been relatively healthier compared to Hissar II and III (see below: periodontal disease and periapical lesions). These changes in oral-health support the hypothesis that cultural changes at *Tepe Hissar*, particularly at Hissar II and III, impacted on their subsistence economy, diet, and general health (Hypothesis 3). The data show that both sexes in each period experienced similar rate of dental disease, except for caries in Hisser I, attrition in Hisser II, and AMTL in Hisser III, where males were suffered more than femals, suggesting possible differences in diet between the sexes (Walker and Hewlett, 1990; Lukacs, 1992; Petersen, 2003; Vargas-

Ferreira et al., 2014). Comparison between males at *Tepe Hissar* showed a significant increase in the prevalence of periapical lesions and attrition in Hissar II, which declined slightly in Hissar III, but based on teeth affected, the rate of periapical lesions increased marginally in Hissar III. There were no significant differences by period for females. Unfortunately, there are few bioarchaeological report available regarding dental diseases among ancient populations from Iran for comparative study (e.g., Rathbun, 1984).

(i) Dental caries

Half the individuals (with preserved teeth) from Hissar I suffered dental caries. In Hissar II, almost a quarter of individuals were affected, and in Hissar III one third of individuals (Table 8.5, Figure 8.6). The rate (individual with preserved teeth affected) in Hissar II (24%) and Hissar III (35%) is within the range of 3%-43% and 36% (individuals affected) reported by Rathbun (1984:150) for Neolithic, Bronze and Iron Age Iranian and Mesopotamian populations, respectively. However, it is lower than the rate reported from an agricultural population (43.6% individuals, 6.8% teeth) from Bronze Age Harappa (2500-2000 B.C.), an Indus-valley Civilization in Pakistan (Lukacs, 1992).

Table 8.5. Dental caries prevalence rates at *Tepe Hissar*

Period	Male		Female		Indeterminate		Total			
	Individuals	Teeth	Individuals	Teeth	Individuals	Teeth	Individuals		Teeth	
	%		%		%		%	*n*	%	*n*
Hissar I	78%	9%	25%	1.8%	0%	0%	50%	18	5.5%	306
Hissar II	30%	2.4%	21%	2.2%	0%	0%	24%	25	2%	407
Hissar III	37%	6%	35%	5.6%	17%	1%	35%	163	6%	2280

The frequencies of caries for each period reflect the nature of the diet. Sugar consumption is found to be one of the main aetiologic factors for dental caries (Petersen, 2003).

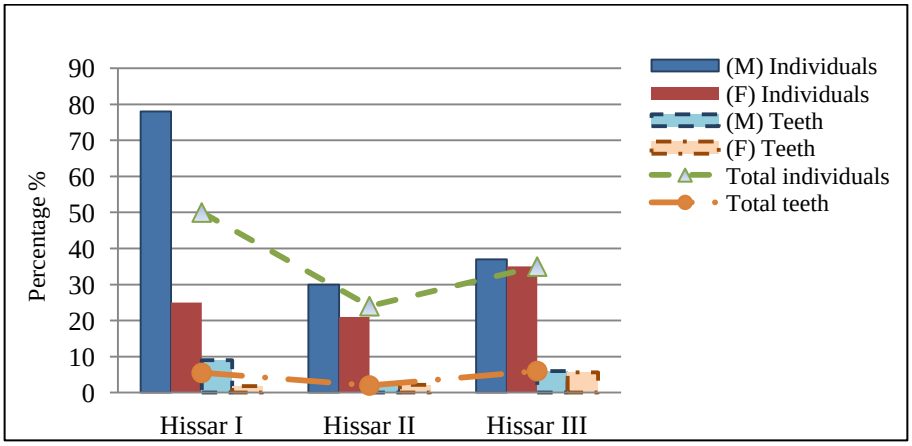


Fig 8.6. Dental caries prevalence rates at *Tepe Hissar*, by sex and period: M/male, F/female

Research indicates a correlation between dental caries and subsistence changes in past populations (Jurmain, 1990; Alder and Turner, 2000) and also in living populations (Navia, 1994). Dental caries frequency was higher in agricultural societies who consumed more fermentable carbohydrates and starchy plants, but it was less common among populations with a diet based on more animal protein and marine foods, with little or no carbohydrate (Sealy et al., 1992; Schollmeyer and Turner, 2004; Hillson, 2008a:112). Based on worldwide survey of populations from different subsistence groups, Turner (1979) indicates a lower prevalence of caries in hunting and gathering economies (1.7%) compared to mixed economies (4.4%), and agriculturally based populations show the highest rate of caries at 8.6% of teeth affected. Larsen (1987) also indicates a similar trend for dental caries among prehistoric pre-agricultural and agricultural populations from the Georgia (USA) coast; pre-agricultural teeth showed 1.3% were affected by caries while teeth of people practicing agriculture showed a 11.6% rate.

The current data suggest that caries rates (per teeth) at Hissar I and III are consistent with a mix-economy (e.g., carbohydrates and animal proteins). However, Hissar II teeth showed more similarity to hunter-gathering/pre-agricultural populations, with more of a tendency towards consuming animal protein and low carbohydrate plant foods, suggesting a different subsistence economy for Hissar II compared to Hissar I and III. The rate of caries for teeth affected for Hissar II (2%) is comparable with the rate in Mesolithic (8300-4200 B.C.) populations of Europe (1.9%) (Meiklejohn et al., 1984). Despite the heterogeneity between periods in the prevalence of caries, no significant differences were found neither in individuals affected or in the total teeth affected, suggesting these differences were minor.

Nevertheless, the data from Hissar I and III (mixed-diet) are consistent with the isotopic analysis (C/N), but not for the data from Hissar II. The carbon and nitrogen stable isotopic data indicate a dietary intake of carbohydrates and animal proteins (mixed-diet) for all three periods at *Tepe Hissar*, but the quantity or type/class of carbohydrates food (e.g., honey, fig) or animal protein intake is not known (see section 8.5). Moreover, archaeological evidence such as mortars (for crushing cereals) and mullers (for grinding cereals) discovered from Hissar I show an agricultural society where wheat or barley was present as a crop and people may have consumed a mixed-diet based on agricultural foodstuffs and domestic (e.g., sheep, cattle) and wild (e.g., gazelle, ibex, mouflons, and birds) animals (Schmidt, 1937:298). Archaeobotanical

studies also showed that the subsistence economy in Hissar II and III was based on agriculture with evidence of intentional diversification of crops (e.g., wheat and barley, legumes) and the utilization of local fruits (e.g., grapes, olive, dates- Costantini and Dyson, 1990). In addition, archaeozoological evidence indicates the contribution of domestic and wild mammals, birds and a considerable amount of freshwater fish to the subsistence economy of Hissar III inhabitants (Mashkour and Yaghmayi, 1998, Radu et al., 2008). However, there is a lack of information regarding faunal remain evidence from Hissar II and the only report available indicates evidence of a sizeable quantity of freshwater fish bones (e.g., *ciprinidae*) from this period (Tosi and Bulgarelli, 1989:45-47), which indicates that these fish were most probably consumed by the inhabitants.

The frequency of dental caries in Hissar I males was 53% (individuals) and 7.2% (teeth affected- significant) higher than in females. This is similar to that reported by Rathbun (1984:150) for both Iranian and Mesopotamian Bronze and Iron Age sites, where males showed more caries than females. However, other population studies show relatively higher frequencies of dental caries in females than males (e.g., Larsen et al., 1991; Temple and Larsen, 2007). The differences in caries rate between males and females in Hissar II and III were insignificant. The higher frequency of caries in males from Hissar I may have been related to different dietary preferences and males may have access to a diet lower in animal protein, but higher in carbohydrates (e.g., sticky fruits, honey) than females. It is assumed that the Hissar I females, with a 1.8% caries rate (teeth affected), may have had more access to animal protein diet than the males (9% teeth affected). The female percentage is more similar for a hunting and gathering economy, while that for males is more similar to an agricultural economy. These data, however, are not consistent with the isotopic data, which shows a similar rate for carbon and nitrogen for both sexes in Hissar I. However, as already mentioned, males may have consumed more sugar which cannot be recognised in isotopic analysis (see above). The decline in male/female differences in caries (teeth affected of the total) in Hissar II and III reflects a relative decline in dietary differences between the sexes in these periods, suggesting males and females had access to similar dietary resources. This data corresponds to the stable isotope data from these periods showing similar rates for carbon and nitrogen for both sexes in Hissar II and III (see section 8.5).

It is known that the development of dental caries is related strongly to age (Hillson, 2008b:313), but this was not the case for people at *Tepe Hissar*. The data

showed (Figure 8.7) people from different age-categories suffered caries lesion equally and probably had access to similar amounts of sugar.

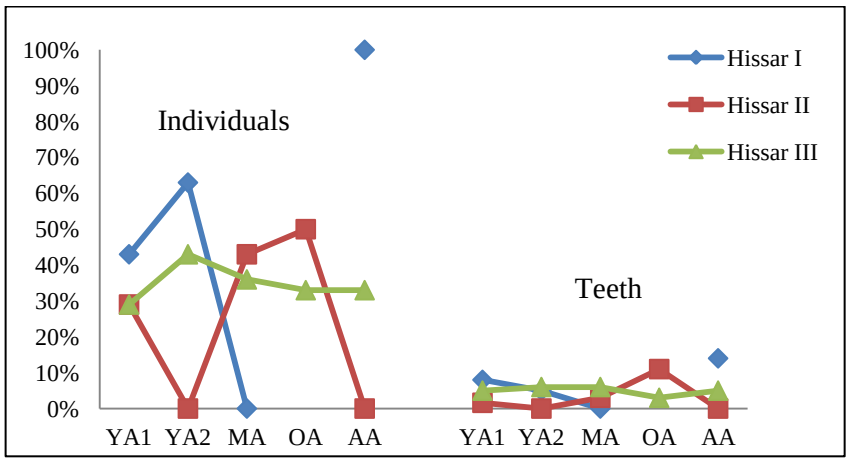


Fig 8.7. Dental caries prevalence rates at *Tepe Hissar*, by age and period

Overall, these data reject the hypothesis that events occurred in *Tepe Hissar*, particularly in Hissar II and III, and impacted on their subsistence economy and the diet people ate (see Hypothesis 3). Nevertheless, the method used for recording, and survival of dental remains will greatly affect the caries data presented (Hillson, 2008b:314). Although carbohydrate-rich food is the main reason for dental caries, it is also recognized that the cause of dental caries cannot be reliably determined since caries have a multi-factorial aetiology (Navia, 1994). Therefore, factors such as food-processing methods (e.g. that might produce a soft diet), dental attrition (e.g., severe attrition can make caries invisible to the naked eye), fluoride in the water supply, tooth crown morphology, DEH (weakens the tooth and makes it more susceptible to caries), lack of oral-hygiene, or dental enamel trace element composition (Larsen, 1987) may all variously have influenced caries prevalence rates observed among the *Tepe Hissar* people. The high prevalence of AMTL and dental attrition at Hissar II and III may also have affected the accuracy of recording caries especially for Hissar II (see below).

(ii) Calculus

About half of the individuals in both Hissar II and III suffered dental calculus, but in Hissar I a quarter of individuals were affected. A diet rich in protein, along with poor-oral-health promotes the formation of dental calculus (Arabaci et al., 2013), but some bioarchaeological studies show a positive correlation between dental calculus and a carbohydrate-rich diet associated with an agricultural economy (Eshed et al., 2006). Nevertheless, the occurrence of dental calculus in each period at *Tepe Hissar* may indicate poor-oral-health for some individuals, and the data showed that both sexes and

different age-groups in each period were affected equally. The data showed no significant differences in the prevalence rate of calculus between periods. However, due to post-mortem damage, many teeth (particularly from Hissar II and III) had clear signs that calculus had been lost post-mortem. In addition, many teeth were missing both ante- and post-mortem, which may have affected the accuracy of the data for dental calculus frequency as for all dental diseases at this site.

(iii)Periodontal disease

Overall, the data showed significant changes in the prevalence of periodontal disease in individuals for pooled sexes over time (Table 8.6). None of the Hissar I inhabitants suffered this disease, suggesting better oral-health in this period. However, the prevalence increased sharply in individuals at Hissar II (67%), and then dropped significantly at Hissar III (18%). Overall, this pattern would suggest differences in oral-health and diet as contributing factors for periodontal disease seen between and within periods at *Tepe Hissar*. This finding supports the hypothesis that cultural changes at *Tepe Hissar*, particularly between Hissar I and II, impacted on subsistence economy/diet and health of individuals from these periods (Hypothesis 3), and this was the same for both sexes in each period.

Table 8.6. Periodontal disease rates at *Tepe Hisser*

Period	Male		Female		Total			
	Individuals	Teeth	Individuals	Teeth	Individuals		Teeth	
	%		*%*		*%*	*n*	*%*	*n*
Hissar I	0%	-	0%	-	0%	18	-	-
Hissar II	40%	-	25%	-	67%	27	-	-
Hissar III	23%	-	12%	-	18%	169	-	-

Modern studies reveal that today almost 5-15% of most populations in the world suffer sever periodontal disease (Petersen, 2003). However, the deterioration in periodontal health in Hissar II (67%) would suggest poor-oral-health, a change in subsistence and diet to hard-textured foods, or extreme extra-masticatory use of the teeth in this period (e.g., dietary and non-dietary) or some combination. This rate was much higher than the modern range (see above) but closer to the rate of periodontal disease from the Neolithic (60%) and Bronze-Iron Age (52%) populations from Mesopotamia (Rathbun, 1984:150).

The decrease in periodontal disease in Hissar III indicates better oral-health and perhaps a change in diet with softer-texture foods, or less mechanical demands on teeth, compared to Hissar II, this rate being 3% higher than the modern range. Differences

between males and females in Hissar II and III in the rate of periodontal disease were small, although males suffered more than females in both Hissar II and III. Periodontal disease increased significantly among older individuals in Hissar II and III (Figure 8.8). In Hissar II, YA1 and YA2 adults did not experience periodontal disease, but nearly three-quarters of the MA and OA adults had this disease, suggesting that oral-health decreased with increasing age in Hissar II. However, in Hissar III almost 10% of young adults between 26 and 35 years old (YA2) showed periodontal disease which increased gradually among MA and older individuals; the differences were significant. A decline in oral-health in Hissar III started at a younger age than Hissar II, possibly due to metabolic disease, diet, heavy attrition, caries, or periapical lesions. The rate of the last three dental pathological conditions was higher for YA2 in Hissar III compared to YA1 in this period.

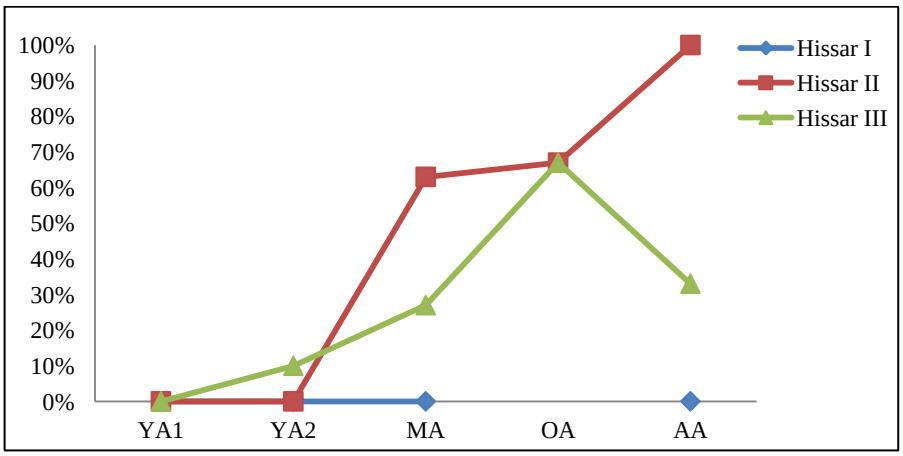


Fig 8.8. Periodontal disease rates at *Tepe Hissar,* by age (individuals affected)

(iv) Periapical lesions

The frequency of periapical lesions was significantly lower in Hissar I individuals (17%, 1% per teeth) compared to Hissar II (63%, 8.3% per teeth) and Hissar III (60%, 8% per teeth), but Hissar II and III showed similar rates (Table 8.7, Figures 8.9-10). People at Hissar I had better oral-health than at Hissar II and III. This again supports the hypothesis (Hypothesis 3) that the changes that occurred at *Tepe Hissar*, and particularly between Hissar I and II, impacted on general health and subsistence economy. The high prevalence of periapical lesions in Hissar II and III may have been related to dental caries, severe dental attrition, crown or root fractures, periodontal disease, or perhaps a combination of these factors (Robertson and Smith, 2009), and may have been the cause of the higher prevalence of AMTL and periodontal disease in these periods, particularly in Hissar II.

Table 8.7. Periapical lesions prevalence rates at *Tepe Hisser*

Period	Male		Female		Indeterminate		Total			
	Individuals	Tooth sockets	Individuals	Tooth sockets	Individuals	Tooth sockets	Individuals		Tooth sockets	
	%		%		%		%	*n*	%	*n*
Hissar I	22%	1%	12%	1%	0%	0%	17	18	1	417
Hissar II	70%	8.6%	63%	8.4%	0%	0%	63	27	8.3	723
Hissar III	66%	10%	56%	7%	33%	3%	60	169	8	4312

Comparison of *Tepe Hissar* males (Table 8.7) showed a significant increase in periapical lesions (7.6%) from Hissar I to Hissar II (of tooth sockets), which continued increasing to about 1.4% (of tooth sockets) higher among males from Hissar III compared to Hissar II. This suggests that oral-health deteriorated in Hissar II and III males, due to changes during these periods, but this was not the case in Hissar I males. However, the individuals affected also showed a significantly similar pattern of decline in oral-health, although Hissar III males showed slightly better oral-health (4%) than Hissar II males.

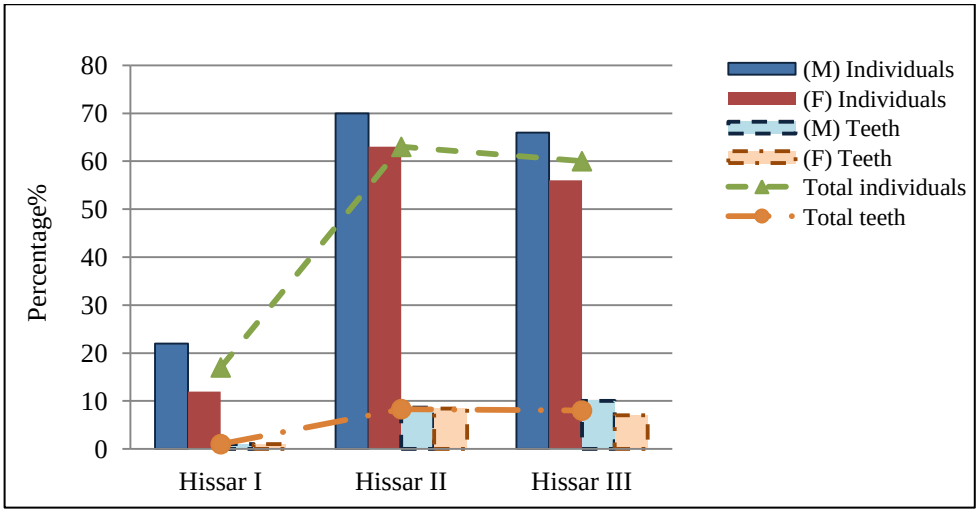


Fig 8.9. Periapical lesions prevalence rates at *Tepe Hissar*, by sex and period: M/male, F/female

Female oral-health (Figure 8.9) declined in Hissar II, showing 7.4% (of tooth sockets; 63% individuals) more periapical lesions compared to Hissar I (1% of tooth sockets; 12% individuals), but oral-health seems to have improved slightly (1.4% of tooth sockets) among Hissar III females (56% individuals), but these differences in females were minor. These data indicate that males possibly suffered poorer oral-health over time compared to females at this site, suggesting they may have been more affected by socio-cultural-economic changes than females. Rathbun (1984:150) also indicates a higher frequency of periapical lesions in males from Bronze and Iron Age Iran, but he did not indicate the possible reason. A comparison of males and female in

each period showed minor differences; this may reflect relatively similar dental health or subsistence for both sexes.

The rate of periapical lesions increased with age in Hissar III, and was significant both for individuals and tooth sockets affected (Figure 8.10). There was no association between periapical lesions and age in Hissar II or Hissar I, and all individuals from different age-groups experienced almost similar rate of this disease. However, YA1 individuals (all females) from Hissar II showed poor-oral-health with a higher percentage of periapical lesions (57% of individuals; 4.6% of tooth sockets) compared to individuals of similar age from Hissar III or Hissar I. This suggests that oral-health declined at a younger age in Hissar II. Just 1% of the individuals from the YA2 group from Hissar I suffered periapical lesions but none of the YA1 and MA individuals showed this lesion.

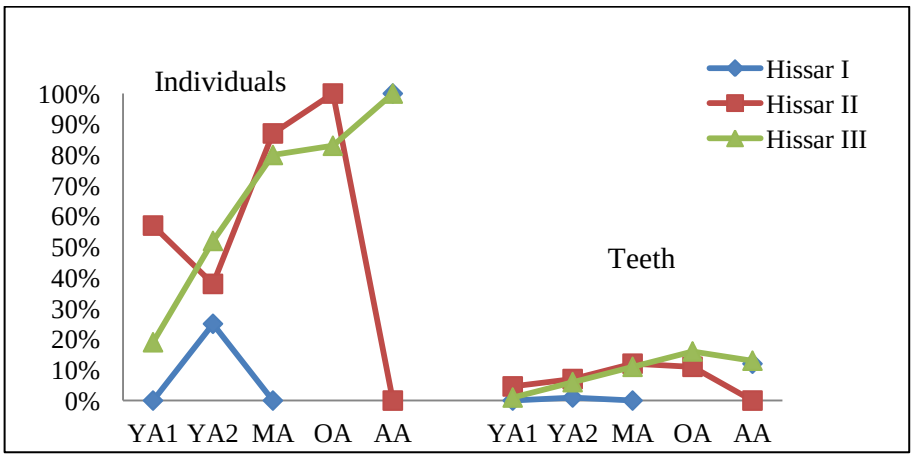


Fig 8.10. Periapical lesions prevalence rates at *Tepe Hissar*, by age and period

(v)Ante-mortem tooth loss (AMTL)

The data show that people in each period experienced different frequencies of AMTL (Table 8.8, Figures 8.11-12). Almost 25% of individuals from Hissar I were affected, and in Hissar II and III nearly half and three-quarter of individuals showed AMTL, respectively. The prevalence rate for Hissar II (14% tooth affected) was almost similar to the Bronze Age (3rd millennium B.C) of Shahr-i Sokhta (15% tooth affected), Iran (Lorentz, 2010). The high rates of AMTL in Hissar II and III individuals may have been caused by advanced dental wear, periapical lesions, severe periodontal disease, or calculus, trauma, advanced dental caries, poor-oral-health, or perhaps nutritional deficiency (e.g., scurvy). The use of teeth as tools may have been another reason for AMTL in people from Hissar II and III. Petersen (2003) in the World Oral-health Report (2003) indicates severe periodontal disease as one of the dental conditions which

affects about 2% of youths during puberty, resulting in premature tooth loss worldwide (Petersen and Ogawa, 2005).

Table 8.8. AMTL prevalence rates at *Tepe Hisser*

Period	Male		Female		Indeterminate		Total			
	Individuals	Teeth	Individuals	Teeth	Individuals	Teeth	Individuals		Teeth	
	%		%		%		%	*n*	%	*n*
Hissar I	22%	1%	38%	4.8%	0%	0%	28%	18	2%	417
Hissar II	60%	9.7%	75%	17%	0%	0%	67%	27	14%	723
Hissar III	54%	14%	43%	10%	0%	0%	47%	169	11%	4312

Females displayed a higher rate of AMTL in Hissar I and II compared to males (insignificant). However, Hissar III males showed more AMTL compared to females (significant:individual and tooth count-Table 8.8, Figure 8.11). This finding suggests males had poorer oral-health than females in Hissar III, perhaps due to differences in subsistence/diet or due to the use of their teeth as tools. A comparison between periods showed that AMTL rates increased through time (insignificant).

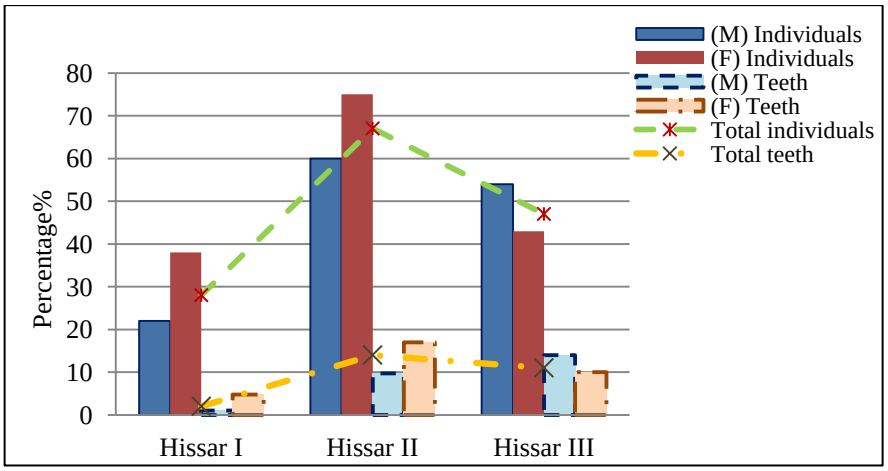


Fig 8.11. AMTL prevalence rates at *Tepe Hissar*, by sex and period: M/male, F/female

The current data showed a minor correlation between AMTL and age for the Hissar I and II period (Figure 8.12), suggesting that all individuals from different age-groups were affected equally. However, the differences in the frequency of AMTL among all age-categories were significant for Hissar III for both individuals and teeth affected. The data showed older individuals from this period experienced a higher rate of AMTL and poor-oral-health compared to younger individuals.

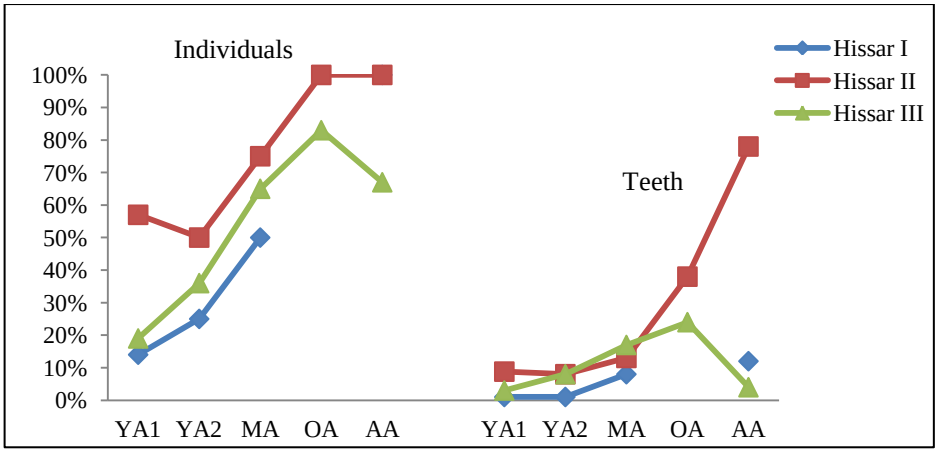


Fig 8.12. AMTL prevalence rates at *Tepe Hissar*, by age and period (individuals and teeth affected)

(vi)Tooth wear

Advanced dental wear (grades 7 and 8, Smith (1984)- see Figure 8.13) were only considered to avoid the effect of increasing age and to assess dietary behaviour more precisely. The data show that people in each period experienced advanced dental attrition. Almost a quarter of individuals from Hissar I were affected, and in Hissar II and III nearly half of the individuals showed advanced dental attrition (Table 8.9 and Figures 8.15, and 8.16).

Table 8.9. Advanced tooth wear prevalence rates at *Tepe Hisser*

	Male		**Female**		**Indeterminate**		**Total**			
Period	Individuals	Teeth	Individuals	Teeth	Individuals	Teeth	Individuals		Teeth	
	%		*%*		*%*		*%*	*n*	*%*	*n*
Hissar I	22%	4%	12%	0.90%	100%	38%	22%	18	6.90%	306
Hissar II	80%	38%	23%	7.50%	0%	0%	46%	24	19.60%	407
Hissar III	56.50%	36%	48.50%	19%	50%	20%	53%	164	28%	2280

Factors such as dietary behaviour, subsistence economy, food preparation techniques, or the texture of food consumed (e.g., raw plant materials, raw meat), or some combination of these factors may have caused heavy attrition. However, differences between individuals and the influence of genetic factors in tooth composition and morphology should be considered. The high percentage of extensive tooth wear in Hissar II and III individuals may reflect the introduction of a "coarse-diet" with more grit and fibre in the food (e.g., the use of quern stones for making flour from cereal grains, and consumption of various nuts and seeds), or the effect of sand and desert in the air and also in food, or inadequate food preparation time (e.g., uncooked or partly cooked-food), or possibly the consumption of dried meat/fish or bone which require extensive chewing which would greatly accelerate dental wear. On the other hand, it is assumed that a low frequency of heavy dental wear in Hissar I may indicate

the consumption of soft and/or less gritty foods. The presence of many fish remains from Hissar III showed that people possibly consumed dried or salted fish (Radu et al., 2008) and this may have been the case for Hissar I and II as well.

Fig 8.13. Severe dental attrition on the teeth of an individual from Hissar II (33-16-30, left) and Hissar III (33-23-153, right)

The majority of individuals in Hissar II and III exhibited highly angled occlusal wear on all molars, with a large reduction in height of the buccal part of the crown relative to the lingual side (Figure 8.13); this pattern of wear in *Tepe Hissar* may indicate a reliance on an agricultural economy (Smith, 1984). However, other studies have noticed greater wear angles in foragers than in agriculturalists (Lubell et al., 1994). Heavy attrition on the anterior teeth of some individuals from Hissar II and III, with a pattern of flat or oblique angled wear (lingual- Figure 8.13), however, suggests the use of the anterior teeth in the initial preparation of food (e.g., foragers have more rounded wear, while agriculturalists show cupped wear) the use of the teeth as tools in these periods, for example in the manufacture of various goods into artefacts (Larsen, 1987:256), or it may have occurred due to gastric-regurgitation (Ogden, 2008). Examination of the teeth of Hissar II and III individuals showed that the maxillary teeth wear more rapidly than the mandibular ones. The evidence of a non-dietary use of teeth was observed on some premolars and molars from Hissar II and III (Figure 8.14), suggesting cultural practices were possibly another factor, along with diet, that promoted rapid and heavy tooth wear in Hissar II and III. Nevertheless, the higher rate of heavy attrition in Hissar II and III may have been one of the reasons for poor-oral-health, the high rate of AMTL and periapical lesions, and extensive periodontal disease in these periods.

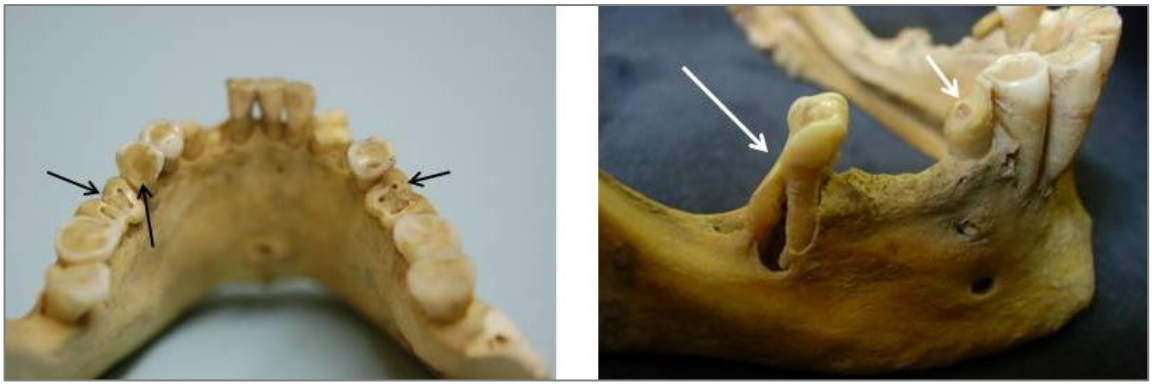


Fig 8.14. Severe dental attrition on the lower M1 and PM2 (left), and pronounced flat attrition on the distal surface of right lower M3 which continued onto the root, and heavy attrition on the right PM2 (right), indicating possible use of teeth as tools

Although the differences in the rate of severe dental attrition between periods when the sexes were pooled were not significant, the differences were significant among males, and Hissar I males experienced the lowest rates of advanced dental attrition, which sharply increased in Hissar II. Individual tooth counts also indicate an increase in heavy attrition in Hissar II compared to Hissar I. However, the rate declined among Hissar III males. These data suggest a significant change in diet and subsistence economy, and/or food preparation methods over time at *Tepe Hissar*. It is suggested that Hissar II males consumed more coarse/gritty diets than those in Hissar I, but Hissar III males probably had access to a less coarse/gritty diet compared to Hissar II. However, the tooth count rates showed closer rates for Hissar II and III males. The pattern of increase in heavy dental wear was also observed in females, with Hissar III females showing the highest rate, but the difference was small.

Males experienced a higher percentage of heavy dental wear than females in each period. However, it was only significant for Hissar II. This suggests dietary and behavioural variability for both sexes in Hissar II. Hissar II males possibly had a different diet or had more access to abrasive foods compared to females. It may also indicate possible differences in division of labour or status between males and females in this period, where males may have used their teeth as tools in occupational activities (e.g., making baskets, stripping of sinew- see Molnar, 1971; Brown and Molnar, 1990).

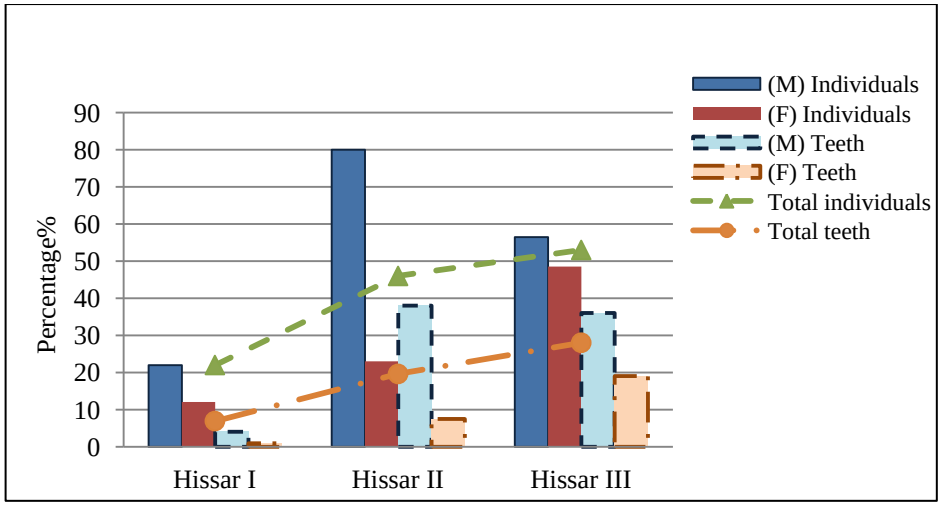


Fig 8.15. Advanced tooth wear prevalence rates at *Tepe Hissar*, by sex and period: M/male, F/female

The frequency of severe dental attrition increased significantly with increasing age in each period and was pronounced in both individuals and teeth affected (Figure 8.16). The YA1 age-group in Hissar I and II did not suffer heavy dental attrition, while 15% (individuals, 3% per teeth) of those in YA1 from Hissar III showed extreme dental attrition. The teeth of individuals showed that the level of advanced attrition was higher among different age-ranges in Hissar III compared to similar age-groups in Hissar II and I.

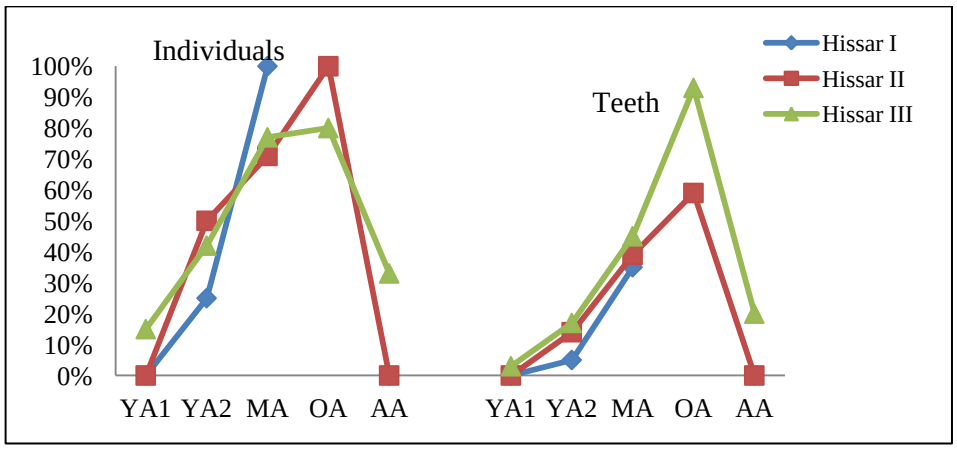


Fig 8.16. Advanced tooth wear prevalence rates at *Tepe Hissar*, by age and period (individuals and teeth affected)

Cultural changes occurred during Hissar II and Hissar III at *Tepe Hissar* which seem to have created risk for developing more nutritional stress and overall poor-oral-health in these periods. The findings of this study corroborate this subsistence and dietary change in Hissar II, with a change in "food preparation" methods and more "abrasive" food, an increase in stress due to the "use of teeth as tools" for industrial work/dental trauma, or a combination of all these factors contributing to declining oral-

health in this period. These factors also influenced oral-health in Hissar III. However, a slight improvement in oral-health in Hissar III compared to Hissar II indicates a possible small change in subsistence or food preparation techniques, suggesting that the cultural transition from Hissar II to Hissar III was possibly not as marked.

Poor oral-health can increase risks to general health and affect nutritional intake, consequently causing nutritional deficiency and affecting quality of life (Petersen, 2003). Sometimes oral disease can be life-threatening (Robertson and Smith, 2009). For example, due to acute dental infections (e.g., caries, dental abscess, periodontal disease) dental microorganisms/bacteria may enter the cranium by spreading along the sinus, body tissues, or through the general blood circulation, cause systemic infection (e.g., endocarditis), and then initiate brain abscesses (Li et al., 1999). In the case of *Tepe Hissar*, however, remarkably poor-oral-health and a high prevalence of dental diseases in each period, as discussed above, may have threatened some individual lives and caused their death.

8.4. Cranial Evidence of Violence: Victims of Battle?

It was hypothesised that people at *Tepe Hissar* experienced violence and tension, due to socio-cultural and economic changes and possible population influxes into the area, particularly in Hissar II and III periods. The data on cranial trauma in individuals from the three periods supports this hypothesis and provides direct evidence for interpersonal human violence at this site. Recent clinical studies showed that the head, face and nasal area are most commonly targeted regions of the body in violent assaults (Brink, 2009; Glencross and Boz, 2014:103), and therefore are useful for measuring levels of violent conflict in archaeological contexts (Lambert, 1997:82). The data on cranial trauma showed that 60 (46%) of the 129 crania examined from the three periods at *Tepe Hissar* presented cranial trauma, with 25 (19%) having evidence of peri-mortem (unhealed/lethal) head injury and 35 (27%) with signs of ante-mortem (healed/nonlethal) head trauma. The majority of healed cranial injuries observed were located superior to the parietal and frontal bones; head trauma above this level are most consistent with a violent blow than an accidental cause such as a fall (Glencross and Boz, 2014:112).

The archaeological data from Hissar I shows the presence of spearheads, copper daggers, and copper blades as grave-goods in some graves from late Hissar I (see Figures 2.5, and 2.14), which were not present in earlier graves (Schmidt, 1937:82),

suggesting an increase in tension, conflict, or competition at the end of Hissar I. These correspond to the first archaeological evidence of grey pottery in late Hissar I, and the archaeological hypothesis of "Grey-Ware" intrusion into the Central Iranian Plateau sites around that time (as discussed in Chapter 2). Archaeologists suppose that Hissar I may have ended due to uncontrollable forces such as epidemic disease, or dynamic changes due to social/political competition, or a decisive external influence, and possibly "Grey-Ware" people implanting their culture on the inhabitants of Hissar I (Schmidt, 1933,1937; McCown, 1942).

The results from the study of cranial trauma showed that one of two crania examined from this period had evidence of peri-mortem injury (Figure 7.89), which may have contributed to the cause of death of this individual. Although the small sample size from this period must be considered. Schmidt (unpublished reports) discovered a communal/mass (?) burial (Plot CG95) containing six skulls with about 10 grave-goods, including beads, cups, and bowls. He dated this burial to early Hissar I, but it is not known why these skulls were grouped together in this way, whether the burial was secondary, the result of a funerary ritual, or a mass burial following interpersonal violence. In fact, this burial seems to be similar to those discovered from Hissar III. None of the skulls from this communal burial were available for the current analysis, but if this is accepted as a mass burial then it can be suggested that the people of the early phase of Hissar I were also faced with interpersonal conflict.

The archaeological evidence from Hissar II shows "tools of war" (Figure 2.7), evidence of frequent destruction of structures, fire, and charred human remains, particularly from the second-half of this period, and abandonment of the site (Howard, 1989:57; Tosi, 1989- see Chapter 2); this collective evidence indicates an increase in violence, conflict, and tension (Lambert, 2002; Guilaine and Zammit, 2005). This was possibly due to an "internal" force, or "external" foreign influences, or both (Schmidt, 1933, 1937:306). The cranial trauma results for Hissar II individuals correspond to the archaeological data and provide direct evidence of interpersonal or intergroup violence, both lethal and non-lethal, having been prevalent at *Tepe Hissar* during this period. This supports the hypothesis that socio-cultural-economic changes at Hissar II were accompanied by aggression. The data showed that 23.5% (4/17) of individuals had peri-mortem head injuries (blunt:50%, sharp:25%, puncture:25%, Figure 7.91), and that males were more victims of violent assault than females. However, the presence of females among homicide victims in this period suggests the conflict may have been on

home territory (Giles and Hyndman, 2004; Buvinić et al., 2013:8). Both females with a lethal head injury were from the YA1 and YA2 age-groups and the males affected were from the YA2 and OA groups. Unfortunately, there is no data regarding violence against non-adults. However, 23.5% (4/17) of individuals from this period showed ante-mortem head injury with a higher rate for females than males; these individuals presented blunt force healed trauma. Individuals with healed cranial trauma may have survived previous attacks, or perhaps these healed wounds imply the existence of interpersonal or intergroup fighting without an intention to kill one's opponent (Glencross and Boz, 2014:117), or perhaps that people received treatment. The frontal and parietal bones were the most frequent target for violent assault. One male (B33) and one female (B26) with evidence of peri- and ante-mortem head trauma, respectively, showed biological distance when compared to other individuals from Hissar II. The grave of the male seemed to be a secondary/disturbed burial without grave-goods, but the female's grave contained a complete skeleton and also four grave-goods. The grave of the second male with the peri-mortem head injury only contained a skull and no grave-goods. However, the other six individuals with cranial trauma did not show any biological distance from unaffected individuals from Hissar II. Thus, the cranial injury data suggest a possible increase in group competition, stress, and physical confrontation during this period. Some of this confrontation obviously caused the death of some individuals and may have been one of the reasons for the collapse of Hissar II.

Archaeological excavations from Hissar III indicate the occurrence of weapons (Figures 2.9), several "mass burials" (Plots DG00, DG01, DG11, CH75, CH85, DH05, DH06, DG96- Figure 2.10) or "communal burials" (Plot DF29-from Schmidt's unpublished archive), with some containing only several adult skulls only (between 5 and 10- Figure 2.10), while others included a number of disarticulated/"interlocked" skeletons of adult individuals (between 5 and 13). On the other hand, the appearance of some single burials with missing skulls, or burials with only a skull, burned buildings and several burned human skeletal remains (Figure 2.11), along with hundreds of flint arrowheads and copper daggers inside and outside this building (Schmidt, 1937:219; Dyson and Remsen, 1989:97-see Chapter 2), the "Warrior" and, finally, evidence of collapse of Hissar III, all suggest that changes during Hissar III may have not have been peaceful (Guilaine and Zammit, 2005). Schmidt assumes invasion of the site by outsiders (Schmidt, 1937:306), with subsequent war and massacre in late Hissar III (unpublished). The cranial trauma results from this period support the hypothesis of

conflict and violence. There is evidence of cranial injury, both lethal and non-lethal for some individuals from Hissar III. Almost 18% (20/110) of people in Hissar III experienced intentional assault, exhibiting peri-mortem cranial injury (blunt:60%, sharp:10%, and puncture:30%, Figure 7.92), and this rate was similar for females and males. The conflict may have been on home territory (Giles and Hyndman, 2004; Buvinić et al., 2013:8) as in Hissar II, and females suffered violent assaults like males. The frequency of peri-mortem trauma was twice as high among females between 18 and 35 years (YA1, YA2) than males from the same age-groups (these data correspond to the mortality data from these age groups- see above). However, MA females showed the highest rate of peri-mortem head trauma compared to younger females. In males, however, the MA age-category, followed by the OA category, showed a higher rate compared to younger males, suggesting males older than 36 years of age may have been more involved and/or were targeted in conflicts than the younger adult males who may have been elsewhere at the time of the conflict. MA males and females experienced the highest rate of deliberate violence and these data, as already mentioned correspond to the mortality data from Hissar III (see Mortality section in this chapter). Among individuals with peri-mortem head trauma, four (2 male and 2 female- from Plots DG10 and DG11) graves only preserved a skull with no postcranial bones being evident, and none had grave-goods. Only two of seven individuals from the communal and mass burials (Plots DF29 and DG00, respectively) exhibited peri-mortem cranial injury, while the rest of the individuals from communal (Plot DF29) and mass burials (Plots DG00,DG01,DH06) showed only ante-mortem/healed cranial trauma. Unfortunately, all the skeletons from the mass burials and communal burial were not available for cranial trauma study. None of the individuals with a pattern of peri-mortem cranial trauma were buried with weapons. Overall, 60% of the individuals with cranial injury did not have any grave-goods, compared to the people without injury (53.6 %, 59/110).

In addition to lethal cranial injury, 28% of males and females from Hissar III showed ante-mortem cranial wounds (see Figure 7.90), suggesting these individuals may have survived from previous violent conflict or that there may have been interpersonal or intergroup conflict and competition without intention to kill, or possibly that people received treatment. Males showed a higher percentage (8%) of healed cranial wounds than females, and they may have experienced more episodes of tension and interpersonal conflict within their community during their lives than females or, as discussed already, they may have survived previous attacks. The prevalence of healed

cranial trauma increased with increasing age for both sexes in this period, and males in each age-group showed a higher rate than females. This finding suggests that people from Hissar III may have experienced different episodes of interpersonal conflict and competition from early adulthood through to old age. The parietal bones exhibited the highest prevalence of cranial injury (both lethal and non-lethal) for both males and females (33% and 28%, respectively) followed by the frontal bone (5% and 9%, respectively). A small % of males from Hissar III showed healed nasal and orbital bone trauma suggesting face-to-face confrontation, but females did not.

Overall, the cranial injury data showed that the population who were buried at *Tepe Hissar* may have experienced a rise in social tension, due to socio-cultural-economic transition, technological sophistication, a possible population increase, and increasing social complexity, which ultimately resulted in interpersonal or intergroup (internal or external forces) competition and lethal violence.

Violent conflict occurred in all three periods, but the small sample size from Hissar I must be noted. The frequency of peri-mortem cranial injury was higher for Hissar II compared to Hissar III. Both sexes were victims of violence in both periods, suggesting that attack probably occurred at the site, and this corresponds to evidence of burnt buildings and charred human skeletal remains discovered from both Hissar II and III. The prevalence rate for ante-mortem head trauma showed that interpersonal aggression was slightly higher in Hissar III compared to Hissar II, and males from Hissar III showed a higher rate compared to females in this period. However, it was the opposite for Hissar II where females exhibited a higher rate. The actual prevalence of violence at *Tepe Hissar* is probably underestimated, since the skeletal remains analysed in this study are a small proportion of the overall *Tepe Hissar* population, and this research only focused on violent cranial trauma because evidence of head injury has proved to be a useful measure of violent conflict in archaeological societies (Lambert, 1997:82); on the other hand, clinical evidence for trauma shows that many interpersonal violent injuries are soft-tissue injuries and would not leave their imprint on bones (Walker, 2001). Unfortunately there are no other studies of violent trauma/or head injury from ancient Iranian populations to compare with.

8.5. Stable Isotope Analysis: Diet

It was hypothesised that cultural-economic transitions and possible population influxes occurred at *Tepe Hissar*, particularly in Hissar II and III, impacted on the subsistence economy and diet of people within and between periods and this also differed between males and females. However, the mean carbon and nitrogen isotope ratios point to similar isotopic compositions, indicating similar diets for all three periods at *Tepe Hissar*, and therefore do not support the hypothesis. Males, females and different age groups in each period also did not show significant differences in diet. These results indicate that the *Tepe Hissar* population had access to similar food resources across the periods and any events that occurred at the site did not significantly affect the diet and subsistence economy of society. Although the isotopic data indicate the possible isotopic composition of human diet, they do not represent the food class, quality or proportion of food consumed (Larsen, 1997; Hedges et al., 2008). Dietary interpretation of ancient populations must also consider that the isotopic composition of humans can be influenced by non-dietary factors such as, environmental changes (e.g., aridity, salinity), biological variability, physiological factors (e.g., starvation, pregnancy, etc.), or bone remodelling rates which may result in greater isotopic variability within a populations (see Chapter 5).

The mean $\delta^{13}C$ values did not change significantly when compared between periods, and are consistent with a C3 terrestrial diet. This is supported by archaeobotanical evidences from Hissar II and III, showing that most plants, including cereals such as wheat and barley, fruits, and vegetables cultivated and consumed at this site belonged to the C3 pathway (van der Merwe and Vogel, 1983; Costantini and Dyson, 1990); none of the botanical samples were from C4 plants. In Hissar I and II, individuals showed a narrow distribution of $\delta^{13}C$ values (1.2‰, 1.3‰, respectively), but a slightly wider range (2.3‰) was found in Hissar III but differences in variance were not significant. The majority of individuals have $\delta^{13}C$ values between -20.4‰ and -19.0‰ (C3 pathway), but four individuals (B80, A60 (male), A97, A99 (female)) from Hissar III have $\delta^{13}C$ values between -18.7‰ and -18.1‰; the $\delta^{15}N$ values of these individuals were between 12.6‰ and 13.3‰, suggesting that they may have had access to a different diet that was not common at *Tepe Hissar*, particularly female A97 ($\delta^{13}C$ -18.1‰, $\delta^{15}N$ 12.8‰). Enriched $\delta^{13}C$ values probably indicate a small C4 terrestrial foods in their diet (either plants or terrestrial animal proteins), or possibly a small amount of marine food (see Chapter 5). These individuals may have come to the site

from another geographical region with a different ecosystem and/or food resources (e.g., marine, C4 terrestrial). Based on dental metrical data, females A97 and A99 showed biological affinities with each other as well as with a group of females from Hissar III. A comparison of burial context and associated grave-goods also show that both were buried in a similar position and similar place, and had six and eight grave-goods, respectively. Male A60 is one of the "warriors" discovered from Hissar IIIC and had almost 40 grave-goods; Schmidt (1933:440-442) suggested that all the warrior burials from this site belong to tribal chiefs. Male B80 had two grave-goods. These two individuals were not examined for biological distance, due to poor preservation. Nevertheless, statistical analysis did not show any correlation between the diet of individuals in this site and their social status. Males showed slightly less negative $\delta^{13}C$ values than females in each period, but this difference was insignificant. This finding suggests females had access to similar food resources as males in each period. However, dental caries prevalence data do not support this suggestion for Hissar I, but support it for Hissar II and III (see section 8.3.2).

The $\delta^{15}N$ values for *Tepe Hissar* showed a small but insignificant increase during time (Hissar I (11.83‰), Hissar II (12.19‰), Hissar III (12.22‰)), suggesting a similar consumption of animal proteins for all periods. The mean $\delta^{15}N$ values for each period indicate consumption of a mixed diet with a significant amount of animal protein (e.g., meat or dairy produce). Zooarchaeological studies from *Tepe Hissar* indicate the presence of different domestic (e.g., cattle, sheep, pig, goat) and wild (e.g., gazelle, red deer) mammal species, as well as birds (e.g., *cf. Alectoris chukar*), and a significant amount of fish (e.g., freshwater *Cyprinidae*) and molluscs (Meder, 1989; Mashkour and Yaghmayi, 1998; Radu et al., 2008), which played an important role in the subsistence economy of the inhabitants at this site. These studies suggest domestic (72.7%) and wild resources (27.3%) contributed to the diet of this population and played an important role in subsistence economy of the site, particularly in Hissar III. The mollusc (*Lymnocardiidae*) and fish remains are similar to those from the Caspian Sea, suggesting there may have been some exchange with the population on the other side of the Alborze Mountains at that time, particularly during Hissar III (Mashkour and Yaghmayi, 1998; Radu et al., 2008). The faunal remains from Hissar III indicate the importance of animal stock breeding (e.g., *Capra*) in the site; cattle were kept for power, and killed when they were older (Mashkour and Yaghmayi, 1998); goats and cattle were the most common domestic animals in Hissar III.

The $\delta^{15}N$ values of humans are elevated relative to foods, whether they are local plants, herbivore/carnivores species, or aquatic resources, by 3-5‰ on average (DeNiro and Epstein, 1981). Therefore, humans with a purely terrestrial diet present bone collagen with $\delta^{15}N$ values about +6 to +12‰ (mean +9‰); a diet based purely on animal protein will exhibit a mean $\delta^{15}N$ value about +12-13‰, and diets based on both plants and animal protein present intermediate values (Dufour et al., 1999, Sealy, 2001). However, local conditions such as soil salinity or dry/water stressed environments (see Chapter 5) can increase the $\delta^{15}N$ values in plants and animals living in those areas, consequently increasing nitrogen values in other trophic levels and the whole foodweb. Lying in an arid or semi-arid region such as the Damghan plain, *Tepe Hissar* is likely to show a large distribution of $\delta^{15}N$ values in plants and animals. Unfortunately, there is no available information regarding the $\delta^{15}N$ values or even $\delta^{13}C$ values (modern or ancient) for *Tepe Hissar* botanical or faunal species to predict the diet of this population. There were no animal bone samples available for isotope analysis. However, the nitrogen values for domestic (8.0‰ to 12.0‰, mean=10‰) and wild (6.9‰ to 10.2‰, mean=8.5‰) herbivores, and dogs (11.6‰ to 14.5‰, mean=13‰) from another arid area in the Central Iranian Plateau (Qazvin plain, Figure 8.17) were considered as a base for the *Tepe Hissar* human isotopic data (Bocherens et al., 2000-see Chapter 5). It was expected that individuals with a purely vegetarian diet at *Tepe Hissar* would exhibit a nitrogen value similar to domestic herbivores from the Qazvin plain (mean=10‰). However, the carbon values for the terrestrial domestic animals from Qazvin plain were more enriched (-16.6‰ to -19.0‰, mean= -17.8‰- Bocherens et al., 2000) than for the individuals from *Tepe Hissar*. Therefore, it could be assumed that the *Tepe Hissar* environment and climate was possibly less arid or less saline compared to Qazvin region and the high nitrogen value in this site may have had no link to aridity or environmental conditions, as on the Qazvin plain (Bocherens et al., 2000), since the majority of individuals exhibited carbon values lower than -19.0‰. Therefore it seems that other factors, for example high animal protein diet and/or freshwater fish, may have been responsible for high nitrogen values in *Tepe Hissar* (see below).

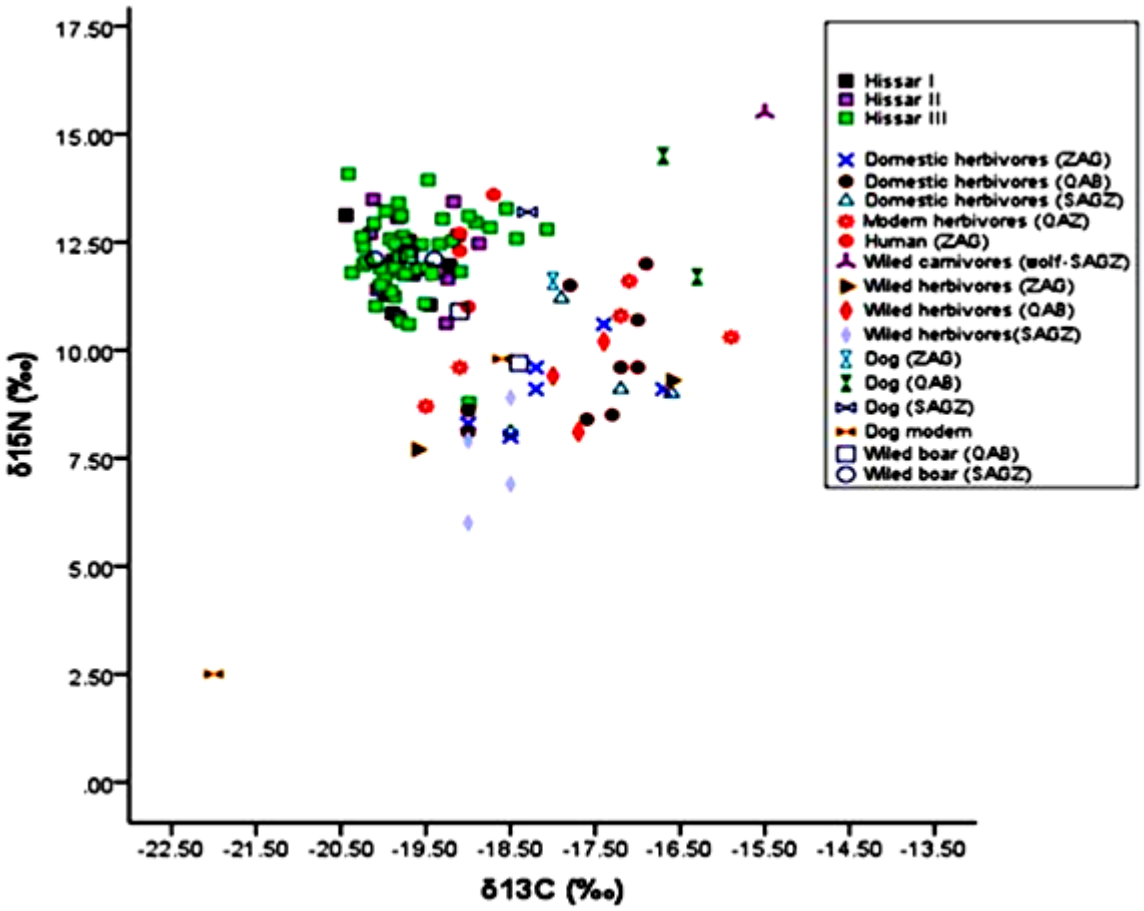


Fig 8.17. Comparison of isotopic data between *Tepe Hissar* and *Qazvin plain* (including data from Bocherens et al., 2000)

The distribution of $\delta^{15}N$ values was slightly narrower for Hissar I compared to Hissar II and III, but was the same for both sexes (1.2‰), suggesting similar variability in access to animal protein foods by males as well as by females in Hisser I. There were two individuals who exhibited higher $\delta^{15}N$ values (A20 (13.1‰), A5 (12.5‰)) compared to the rest of the individuals in this period, their $\delta^{13}C$ values being 20.4‰ and 19.7‰, respectively. These data suggest that these individuals may have had a different diet from the rest of the people in Hissar I, probably higher in animal protein or with small quantities of freshwater resources (e.g., fish), particularly for A20, or perhaps "manured" cereals in their diet (Müldner and Richards, 2005; Vika and Theodoropoulou, 2012- see Chapter 5). The excavations uncovered fish bone and freshwater resources from the Hissar I period (Meder, 1989, Thornton, 2009) as well as evidence of a river near *Tepe Hissar* (Roustaei, 2006; 2010). None of the individuals from Hissar I showed a purely vegetarian diet or any evidence for C4 foods.

Three males and three females from Hissar II showed high $\delta^{15}N$ values (between 12.5‰ and 13.5‰) compared to the rest of the individuals from this period, their $\delta^{13}C$ values were between -20.2‰ and -18.9‰ and consistent with a terrestrial C3 diet,

suggesting consumption of animal proteins, and possibly input of a small amount of protein from freshwater resources in the diet (Müldner and Richards, 2005). The archaeological excavation found many fish bones (e.g., *Ciprinidae*) from the Hissar II period (Tosi and Bulgarelli, 1989), supporting consumption of freshwater fish in this period. Two females (A42, A38) from this period exhibited a lower $\delta^{15}N$ value (10.6‰, 10.8‰, respectively) compared to other females and males; their $\delta^{13}C$ values were -19.3‰ and -19.8‰, respectively, suggesting a mixed-diet with lower animal protein and possibly more C3 plants. However, these differences were minor. None of the individuals from Hissar II showed a purely vegetarian diet.

The overall range of $\delta^{15}N$ values for Hissar III was 10.6‰ to 14.1‰, indicating that some individuals had higher $\delta^{15}N$ values than might be expected from a terrestrial diet. Nine individuals (five males, four females) exhibited the highest nitrogen values (13.1‰ to 14.1‰) in Hissar III and their carbon values were between -20.4‰ to -18.6‰. Therefore, it seems that these individuals consumed a mixed-diet including terrestrial animal protein, and probably a small quantity of freshwater resources. The carbon and nitrogen values (-18.6‰ and 13.38‰, respectively) for male B80 suggest a possible input of marine food, or C4 terrestrial foods to his diet. As discussed above, three other individuals from this period also showed more positive carbon values. Only one individual showed a low nitrogen value (8.79‰), suggesting this individual possibly had a diet based on pure terrestrial C3 plants with a very small/or no animal protein component. The rest of the people in this period appear to have had different mixed-diets based on terrestrial C3 plants and animal proteins (perhaps both domestic and wild herbivores) and freshwater resources (Mashkour and Yaghmayi, 1998; Radu et al., 2008). The occurrence of people with different stable isotope carbon and nitrogen ratios suggests the presence of new comers into the site.

8.6. Summary

This research found (also see Table 8.10) that the socio-cultural-economic changes and events reflected in the archaeological data at *Tepe Hissar* were not accompanied by large scale population replacement/immigration/invasion; however, there was more small scale population replacement over time, although these changes were accompanied by interpersonal violence. The biological affinity data showed each period was occupied by different groups of people with possibly different genetic makeups, who represented similarity and dissimilarity in biological relationships with

each other. It also showed a pattern of biological continuity from Hissar I to Hissar III, while there were also some individuals/groups of people with a different genetic makeup buried during each period.

The data also indicates that these socio-cultural-economic changes did not significantly impact on the general health of people over time, particularly those buried during Hissar II and III, however, the inhabitants from each period experienced different frequencies of stress and disease, and periods of malnutrition; both sexes were affected equally in each period. However, a significant increase in the rate of CO in males from Hissar II compared to Hissar I indicates that the events that occurred during the former possibly impacted the general health of children (possibly boys), but that the changes during Hissar III caused less stress.

The dental disease data showed that cultural changes during Hissar II and III had a significant impact on the oral-health of people from these periods; people buried during Hissar I experienced better oral-health compared to Hissar II and III. This suggests that events occurred during Hissar II and III were accompanied by changes in subsistence economy and diet (e.g., greater consumption of fibrous plants), food preparation techniques (e.g., dried fish/meat or uncooked cereals), and how the teeth were used as tools. Hissar II and III males suffered more attrition and AMTL, respectively, compared to females from these periods; they may have had a different diet or possibly used their teeth as a third hand in occupational activities more than females; suggesting unequal status for both sexes in these periods. Hisser I males suffered more caries than females, suggeting they may have had more sugar food (e.g., sticky fruits, honey) than females in this period.

The carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic data showed that *Tepe Hissar* population had access to similar food resources across all periods, particularly during Hissar II and III. Individuals from each period, both females and males from different age-categories, had a similar diet based on C3 plants and animal protein, as well as a small contribution from fresh water resources. This shows that events occurred at this site did not significantly impact on diet and food resources in each period.

Table 8.10. The research hypotheses, questions and answers

Hypotheses and research questions	Answers
Hypothesis 1: The inhabitants from Hissar I period are a homogenous population and possess close biological affinities, which are represented in the associated material culture; both have continuity within this period.	Partly supported and partly rejected
Questions	
1. Are the data from metrical and non-metrical analysis consistent for all individuals from Hissar I?	Consistent and inconsistent
2. Are the funerary and material culture data consistently the same throughout this period?	Yes
Hypothesis 2a: There are similarities and dissimilarities in biological affinities between individuals/groups of people from the Hissar II and III periods, suggesting influxes of new people	Supported
Hypothesis 2b: There is no biological continuity between the three periods at Tepe Hissar, due to population replacement in each period.	Partly supported and partly rejected
Questions	
1. Are the data from metrical and non-metrical analysis consistent or inconsistent across all individuals from Hissar I, II and III?	Consistent and inconsistent
2. Are the funerary and material culture data consistently the same throughout all periods?	No
Hypothesis 3: The cultural and economic transitions and possible population changes that occurred at *Tepe Hissar*, and particularly in Hissar II and III, impacted on their subsistence economy, the diet people ate, and their general health, and also resulted in a rise in tension and interpersonal violence among this population; this also differed between males and females.	Partly supported and partly rejected
Questions	
1. What type of diet did people from each period eat?	Mixed-diet: terrestrial C3 plants, animal protein, and a small quantity of freshwater resources; similar diet for both sexes
2. What health problems did they suffer?	Metabolic disease (vitamin D deficiency,osteopenia/osteoporosis), dental disease, cribra orbitalia, porotic hyperostosis, DEH
3. Did they experience interpersonal violence?	Yes
4.Were there differences between males and females?	No: equal health status for both sexes in each period (except for caries in Hissar I, attrition in Hissar II, and AMTL in Hissar III, and males showed higher rate)
5. If there were differences, do they suggest anything about the status of males and females in society?	Possible differences in food type, division of labour, or status between males and females in Hissar II and III; males may have used their teeth as tools in occupational activities more than females. Hissar I males may have had access to more starchy/sugar food then females.

This chapter discussed the data in the context of the research hypotheses and questions. The next chapter presents a conclusion of the findings, limitations of the research, and suggestions for future research.

Chapter 9 : CONCLUSIONS

9.1. Introduction

The aim of this study was to investigate if the *Tepe Hissar* populations (Chalcolithic and Bronze Ages (5^{th}- 2^{nd} millennium B.C.)) shared close biological relationships, or if they represented distinct biological groups within and between periods. The research also determines the impact of cultural changes on general health/stress, subsistence economy, diet, and interpersonal conflict within and between the periods analysed, by sex and age (see Chapter 1 and 2). To achieve this aim, a bioarchaeological study of human skeletal remains from *Tepe Hissar* was undertaken using macroscopic (see Chapter 3 and 4) and carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope analyses (see Chapter 5 and 6).

9.2. Research Objective and Hypotheses

The major objective of this study was to understand whether changes reflected in the archaeological material at this site were caused by "biological replacement", or that cultural development occurred without biological changes; and whether the evident cultural changes impacted on subsistence economy and diet, and affected the experience of disease or conflict within and between periods, and between the sexes. To achieve this objective biological data were collected from skeletons from both sexes from each period, including skeletal and dental measurements and non-metric traits, indicators of stress, dental and metabolic disease, as well as cranial trauma. The data were then compared between periods to assess patterns of biological and population change/continuity over time. Dietary patterns, and hence subsistence economy, were explored by conducting stable isotopic analyses of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) and data compared between periods to evaluate the impact of changes in material culture. This was the first application of stable isotopic analysis to Chalcolithic and Bronze Age individuals from *Tepe Hissar*. The bioarchaeological data from this site were then used to test the following hypotheses:

- **Hypothesis 1:** *The inhabitants from Hissar I period are a homogenous population and possess close biological affinities, which are represented in the associated material culture; both have continuity within this period.*

This hypothesis was partly supported and partly rejected. The people from Hissar I were not found to be very homogeneous and it is possible that other individuals or groups of people with different biological backgrounds lived close to the majority biological group buried during Hissar I. Thus, although the archaeological evidence at the site (e.g., painted pottery) showed continuous cultural development without interruption during this period (Schmidt, 1937:44,299), this homogeneity was not present in the biological data (see Chapter 1, Hypothesis 1 and questions 1 and 2, Table 8.10). Despite, poor preservation and a small sample size, this study made a thorough analysis of the limited skeletal remains available for study from this early period.

- **Hypothesis 2a:** *There are similarities and dissimilarities in biological affinities between individuals/groups of people from the Hissar II and III periods, suggesting influxes of new people.*
- **Hypothesis 2b:** *There is no biological continuity between the three periods at Tepe Hissar, due to population replacement in each period.*

Hypothesis 2a was supported for the most part. Biological distance studies from Hissar II showed that the inhabitants from this period were not a homogeneous population and this was seen in both males and females. The data from both metrical and non-metrical analysis were partly consistent and partly inconsistent across all individuals from this period (see Chapter 1- Hypothesis 2a, question 1). Some individuals showed close similarity with each other, in the male and female groups, while some exhibited less similarity, and a few were morphologically isolated (see Chapters 7 and 8). This indicates possible population changes and influxes of new individuals or groups of people with a different genetic makeup into the region during Hissar II. These findings are consistent with the material culture changes (e.g., more diversity in how the dead were disposed of, and pottery- see Chapter 2), and archaeological hypotheses of newcomers at that time. It shows that the cultural changes in the Hissar II period were accompanied by biological changes and perhaps "exchanges" with migrants. A comparison between individuals from Hissar I and II demonstrated that, except for a few individuals, most people buried during Hissar II (both males and females) showed a different biological background to those from Hissar I. Although there is clear evidence for migrants, there was still an indication of biological continuity with Hissar I in skeletons from Hissar II. Therefore, the biological

changes seen for Hissar II were not as large as might be expected with invasion, immigration, or total population replacement of the site. Rather, biological changes reflect a limited introduction of people or individuals from elsewhere into the site, although this was accompanied by increased conflict and tension (see below). These data do not support Hypothesis 2b, since there was evidence of continuity of Hissar I people into the Hissar II period.

Biological distance studies of skeletons from Hissar III showed that the inhabitants were not a strongly homogeneous population and this was seen for both males and females (supports Hypothesis 2a). The data from metrical and non-metrical analysis were partly consistent and partly inconsistent across all individuals from this period. In both sexes, there was a close biological relationship between some individuals/groups, while some exhibited less similarity, and some showed no affinity with the rest of individuals. Overall, the data for Hissar III corroborate those seen for Hissar I and II and that the site was occupied by different individuals/groups of people. This suggests that socio-cultural-economic changes occurred during Hissar III and these may have been accompanied by newcomers with a different genetic makeup. These biological differences also correspond to the evidence of material cultural changes (e.g., increased variety in funerary culture, pottery, and other artefacts - see Chapter 2).

Comparison of biological data between Hissar III and Hissar II partly supports and partly rejects Hypothesis 2b, showing a pattern of biological homogeneity between some individuals from both periods. The data from metrical and non-metrical analysis were not totally consistent across all individuals from this period. Some individuals from Hissar III exhibited a different biological background when compared to people from Hissar II, and there were some Hissar II individuals who were not similar to either Hissar II or to Hissar III people. Overall, the data show a biological continuity between Hissar II and III, while there were also some divergent individuals/groups with a different genetic makeup buried during Hissar III, all corresponding with funerary and other material culture data from these periods (see Chapter 2). This suggests that the changes at the site during Hissar III were not accompanied by a large scale population replacement/immigration or invasion, but rather were limited to small scale individuals/population replacement, although these changes were not peaceful (see below) and accompanied by interpersonal violence at Hissar III. A comparison between Hissar I and III showed similarity between some individuals from these periods and this again allows the rejection of Hypothesis 2b.

Overall, the biological data showed that *Tepe Hissar* experienced population exchanges over time, but they were small scale. The research therefore is able to reject the archaeologically driven hypotheses of wholescale invasion and population replacement at the site. Nevertheless, these data may have been affected by some limitations such as sampling bias, poor preservation, unequal sample size between the periods, and a limited sample, particularly for Hissar II and I when compared to Hissar III.

- **Hypothesis 3:** *The cultural and economic transitions and possible population changes that occurred at Tepe Hissar, and particularly in Hissar II and III, impacted on their subsistence economy, the diet people ate, and their general health, and also resulted in a rise in tension and interpersonal violence among this population; this also differed between males and females.*

This hypothesis was partly supported and partly rejected. The results from the analysis of indicators of stress and metabolic bone disease (see Chapters 7 and 8) showed that the cultural changes and population influxes to *Tepe Hissar* over time did not significantly change the levels of general health and stress at this site. However, people in each period experienced different frequencies of stress, illness episodes, or periods of malnutrition (see Table 8.10, Hypothesis 3, question 2); both females and males were affected by stress equally and the different age-categories during Hissar I and II. However, individuals from different age-categories from Hissar III showed significant differences in prevalence rates for vitamin D deficiency, osteopenia/osteoporosis, and the "total metabolic diseases" category, and the older people experienced higher frequencies compared to younger individuals in Hissar III. However, about 50% of the young adults (YA1, YA2) were also affected, and this may indicate malnutrition, undernutrition or diseases associated with nutritional stress that had affected young individuals during their childhood (Ortner, 1998:32). The high rate of vitamin D deficiency and osteopenia/osteoporosis at *Tepe Hissar* suggests that socio-cultural-economic changes and an increase in industrial activity, particularly during Hissar II and III, may have exposed some individuals (adults and non-adults) to toxic elements such as lead and arsenic which were widely utilized in metallurgical activities at that time (Tosi, 1989; Thornton, 2009). This may have contributed to their susceptibility to vitamin D deficiency and osteopenia/osteoporosis (Dart et al., 2004:1426-8; Yu et al.,

2011). Ostrander (2013- see chapter 8) also found a correlation between rickets and high levels of lead poisoning seen via isotopic analysis.

Comparison of prevalence rates for stress and metabolic disease between the periods at *Tepe Hissar* allows the rejection of Hypothesis 3, showing an insignificant increase in stress and metabolic bone disease over time, with people from Hissar I exhibiting the lowest frequencies, and the rate increasing during Hissar II and III. However, a significant difference was only seen in prevalence rates for CO for males between periods, indicating that males from Hissar II were more exposed to stress and illness during childhood compared to Hissar I males. But, during Hissar III conditions were better and people experienced less frequent episodes of stress compared to Hissar II. This indicates that changes that occurred during Hissar II possibly impacted the general health of children, but living at *Tepe Hissar* during Hissar III was accompanied by less stress. This therefore supports Hypothesis 3. Overall, the data indicate that, despite cultural changes and population movements occurring at *Tepe Hissar* over time, the population likely experienced similar level of stress and poor health and had access to similar food resources during the Chalcolithic to Bronze Age occupation of this site; this is also consistent with the isotopic data indicating a similar diet for people living through all periods at *Tepe Hissar*.

The overall dental disease data support Hypothesis 3, showing significantly better oral-health for Hissar I individuals when compared to those buried during Hissar II and III. However, the prevalence rates for dental disease increased sharply during Hissar II; this was also seen for people from Hissar III. In Hissar III people showed marginally better oral-health than in Hissar II. Changes in culture occurred at *Tepe Hissar*, and particularly during Hissar II and III, and this appears to have significantly affected oral health. This could have been due to changes in subsistence economy and diet, food preparation techniques, or the use of teeth as tools. The significant differences seen were:

- A significant increase in the frequency of periapical lesions during Hissar II compared to Hissar I, and then a slight decrease in Hissar III
- A significant increase in the frequency of periodontal disease during Hissar II, which declined sharply for Hissar III individuals
- A remarkable increase in the frequency of dental attrition and periapical lesions in Hissar II males compared to Hissar I, which declined slightly in Hissar III males

- Caries in Hissar I males were more frequent when compared to females
- Attrition in Hissar II males was more frequent when compared to females
- AMTL in Hissar III males was more frequent when compared to females

Comparison between the periods at *Tepe Hissar*, by pooled sex, demonstrated a significant increase in the prevalence of periapical lesions (also significant for males between the periods) and periodontal disease for people buried during Hissar II, which declined in Hissar III. These data support Hypothesis 3 and show that cultural changes at *Tepe Hissar*, particularly during Hissar II and III, had an impact on oral-health compared to Hissar I. However, people from Hissar III suffered less oral disease (e.g., periodontal disease, periapical lesions), compared to those from Hissar II. Overall, the remarkable decline in oral-health during Hissar II and III could have been associated with a change in diet and subsistence economy, food preparation methods, or extra-masticatory use of the teeth compared to Hissar I. A significantly high rate of attrition corresponds with this finding (see below).

In males, severe dental wear peaked significantly in Hisser II compared to Hissar I, but then decreased slightly in Hissar III. These data support Hypothesis 3 and are consistent with the pattern of periapical lesions and periodontal disease, indicating again a change in diet and subsistence. A comparison between males and females within the periods showed that Hissar II males experienced a significantly higher rate of severe dental wear compared to females. Males buried at *Tepe Hissar* suffered poorer dental health compared to females, particularly during Hissar II; they may have had a different diet, or they possibly used their teeth as a third hand more than females. Severe dental attrition in the people buried during the three periods at *Tepe Hissar* exhibited a significant relationship to increasing age. The study of fish remains from Hissar III suggests that fish had been preserved dried or salted prior to consumption (Radu et al., 2008). This may well have been the case in previous periods as well, and have contributed to heavy dental attrition at this site.

The high rate of caries seen for Hissar I males may have been related to different dietary preferences, and males may have had access to a diet containing a high carbohydrate content compared to females, while females may have had more access to animal protein in their diet. A population surviving on a high animal protein-high fat diet usually does not experience caries, in contrast to a population with a high

carbohydrate and sugar diet where an increase in caries rate is seen (Schollmeyer and Turner, 2004).

Hissar III males exhibited a significantly higher AMTL, compared to females, suggesting males suffered poorer oral-health, and these data supported Hypothesis 3. There was a significant association between AMTL and age for Hissar III, but 19% and 36% of young adults between 18-25 (YA1) and 26-35 (YA2) years old, respectively suffered AMTL. Periodontal disease and periapical lesions in people from Hissar III exhibited a significant relationship to age but here, again, 19% of YA1 were subjected to periapical lesions. A substantial proportion of these lesions among young individuals in this period indicate a chronic condition. Overall, these findings again suggest that males at *Tepe Hissar* suffered poorer oral-health compared to females and this might indicate differences in diet or food types between the sexes, or perhaps males used their teeth as tools more during various activities, particularly during Hissar II and III. There were no significant differences in prevalence rate for calculus between three periods; both males and females were affected equally in each period. Nevertheless, unequal oral-health status for males and females may suggest relatively unequal social status (see Table 8.10, questions 4 and 5).

Results from stable isotope analysis rejected Hypothesis 3 and showed that the inhabitants of *Tepe Hissar* had access to similar food resources across all periods. Individuals from each period, both females and males from different age-categories, had a similar diet based on C3 plants and animal protein as well as a small contribution of fresh water resources (see Chapter 1, Hypothesis 3- question 1). This finding is consistent with archaeobotanical and zooarchaeological data from *Tepe Hisser*, suggesting the plants were mostly wheat and barley, with supplemental vegetables and fruits, and the animals were both wild and domestic. The $\delta^{13}C$ values also indicate that there was no major climate change (e.g., aridity) in the Damghan region from the Chalcolithic to the Bronze Age (5^{th}- 2^{nd} millennium B.C.), since the $\delta^{13}C$ values from each period are consistent with a C3 pathway. Some samples showed different stable isotope carbon and nitrogen ratios, suggesting the presence of new comers into the site (see Chapter 8).

The data on cranial injury provided direct evidence for interpersonal violence and conflict during each period at *Tepe Hissar*, thus supporting Hypothesis 3- question 3. Socio-cultural-economic changes and events that occurred at this site were probably not peaceful and were accompanied by interpersonal violence/conflict. People from Hissar I

may have experienced interpersonal conflict/competition, and this corresponds with the archaeological data and the presence of communal/mass burial, and daggers and blades. However, the sample size from this period was small. The data from Hissar II showed that cultural changes experienced in this period were also accompanied by evidence of aggression and this is consistent with the archaeological data from this period (e.g., weapons, burnt buildings, charred human skeletal remains); males were more victims of violent assaults than females but females showed higher ante-mortem trauma than males. The presence of females with lethal head injuries suggests that the conflict may have happened in a domestic situation (Buvinić et al., 2013:8). Data from Hissar III also showed that cultural changes during this period were not peaceful. Again, this is also consistent with the archaeological data, as seen for Hissar II. The rate of peri-mortem cranial trauma was lower during Hissar III compared to Hissar II, but that of ante-mortem cranial trauma was higher during Hissar III compared to Hissar II. Young females between 18-35 years old (YA1-YA2) were more a target of intentional assault than males from this age-group, and the MA and OA categories showed a higher rate for lethal cranial. The presence of females with lethal head trauma suggests attack/conflict may have occurred on home territory, as seen during Hissar II, perhaps as a result of internal or external forces.

9.3. Limitations

The majority of the limitations for this study have been already discussed in the Chapters 6 and 8. However, the major limitations encountered were, as follows:

- poor preservation,
- unequal sample size for the three periods,
- post-mortem damage,
- sampling bias,
- incompletely recovered skeletons

These are all challenges of studying the archaeological record.

There were also:

- a limited range of recording techniques (e.g., metabolic disease)
- lack of standards to describe the pathological lesions (e.g., scurvy)
- problems with determining the aetiology and interpretation of the skeletal lesions,

- absence of specific recording methods developed on "modern documented" skeletal remains from Iran (e.g. age and sex-estimation methods, along with stature reconstructions),
- lack of access to radiographic analysis during recording of the data,
- few published bioarchaeological studies from ancient Iran,
- lack of access to other skeletal material or bioarchaeological studies from contemporaneous sites/period in Iran for comparative analysis, and
- few published comparative archaeological studies on the *Tepe Hissar* archaeological materials

Finally, regarding the osteological paradox that argues that there are problems of inferring health from prehistoric skeletal samples (Wood et al., 1992), a substantially high prevalence of markers of stress and metabolic bone disease among people buried in each period at *Tepe Hissar* may indicate a "good health history" throughout the occupation of the site, where individuals survived episodes of stress and illness long enough to reach adulthood as seen in the evident chronic healed bone changes. The biases of archaeologically derived skeletal populations, for example individual variations in disease frequency rates and the degree of skeletal expression, genetic variation, which may predispose people to disease, poor preservation of remains, and selective mortality (Wood et al., 1992; Waldron, 1994) must all be taken into account. For example, individuals with few or no pathological lesions may have been exposed to multiple episodes of biological stress but were not strong enough to survive long enough for bone lesions to develop. On the other hand, short periods of stress will not necessarily affect the skeleton. These biases can affect the prediction of health and illness in archeological populations, and they likely influenced the results of this study.

9.4. Suggestions for Future Research

The data collected from the human skeletal remains from *Tepe Hissar* represent a the biological characteristics of the population from the early to late phases of occupation at this site (Chalcolithic and Bronze Age, 5^{th}- 2^{nd} millennium B.C.), and they provide important information about the life histories of this past population; *Tepe Hissar* is also of one of the key sites on the northern Central Iranian Plateau. This study provides a bioarchaeological baseline of data generated using multiple methods, and it is the starting point for potentially fruitful future analyses of human remains from this

and other ancient sites in Iran. This is extremely important for Iranian archaeology and for the future of bioarchaeological research in Iran and neighbouring regions.

Beyond dietary studies using stable isotope analysis, as seen in this study, isotopic analyses of strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) can also be used to clarify the origin of the people from each period at *Tepe Hissar* and to explore the pattern of mobility and migration from different geographical regions (e.g. see Bentley, 2006; Mitchell and Millard, 2009). Extraction and analysis of ancient mitochondrial DNA may also help to reveal a clearer picture of genetic affinity and population movements within and between periods at *Tepe Hissar*, and these data could be compared with available, or future, DNA data from Iran and neighbouring regions (e.g., Central-Asian and Mesopotamian samples). This could not only be used to corroborate the metrical and non-metrical data from this study, but could be used to identify individuals with different genetic backgrounds buried at *Tepe Hissar*. It could also be used to see if population diversity at this site was internally (from other regions in Iran) or externally driven (from outside Iran). On the other hand, a comparison of metrical and non-metrical data from *Tepe Hissar* populations with other contemporaneous populations from the Central Iranian Plateau, and north east Iran, would help to better understand population history at *Tepe Hissar* and possible biological relationships with these regions.

Other advanced analytical methods could also be applied to the skeletal remains. For example, lead analysis of dental enamel could be used to explore any correlations between a high level of lead poisoning and vitamin D deficiency and osteoporosis. Carbon and nitrogen isotopic analysis of animal bones from each period at *Tepe Hissar* would also be useful to have a better picture of diet and subsistence economy of people from each period at this site, and it could also be used to identify any environmental and climate changes at the site.

APPENDIX 1

Recording Form

Adult Skeletal Recording Form– *Tepe Hissar*

Museum Number:	**Skeleton Number:**	**Area/Squar:**
Grave Good:	**Grave Type:**	**Number of Individuals:**
Preservation:	**Period:**	**Age:**
Sex:	**Stature:**	**Cranial Trauma:**
Recorded By:		**Date:**

Summary of dental non-metric data:	
Summary of dental metric data:	
Summary of skeletal non-metric data:	
Summary of skeletal metric data:	
Palaeopathology: Cribra Orbitalia(CO) Porotic Hyperostosis(PH) DEH **Metabolic Disease Dental Disease**	
Isotope samples taken:	**Isotope results:** **Carbon: Nitrogen:**
Note:	

Inventory:

Cranial Bone	L	R	Absent
Frontal			
Occipital			
Parietal			
Temporal			
Sphenoid			
Mandible			
Maxilla			
Palatine			
Orbit			
Nasal			
Zygomatic			
Ethmoid			

C1		T6	
C2		T7	
C3		T8	
C4		T9	
C5		T10	
C6		T11	
C7		T12	
T1		L1	
T2		L2	
T3		L3	
T4		L4	
T5		L5	

Right

Bone	>75%	50-75	50-25	<25%
Ilium				
Ischium				
Pubis				
Scapula				
Clavicle				
Patella				

Left

Bone	>75%	50-75	50-25	<25%
Ilium				
Ischium				
Pubis				
Scapula				
Clavicle				
Patella				

Bone	Prox. J.S	P 1/3	M 1/3	D 1/3	Dist. J.S
Humerus					
Radius					
Ulna					
Femur					
Tibia					
Fibula					

Bone	Prox. J.S	P 1/3	M 1/3	D 1/3	Dist. J.S
Humerus					
Radius					
Ulna					
Femur					
Tibia					
fibula					

Bone	>75%	50-75	50-25	<25%
Sternum				
Coccyx				
Sacrum				

Ribs	complete	Head	End	Fragments

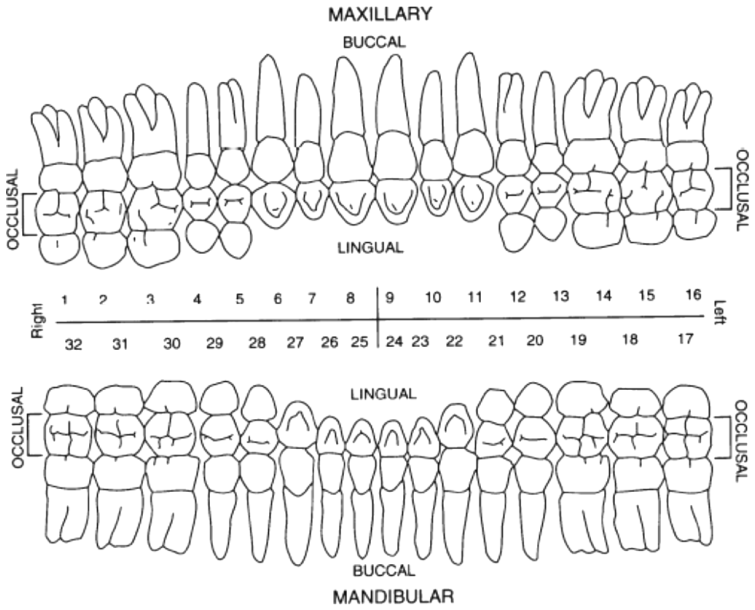
Bone	L/present/complete	R/present/complete	Unsided	Comments
Talus				
Calcaneus				
Tarsals (foot)				
Metatarsals				
Phalanges				
Carpals (hand)				
Metacarpals				
Phalanges				

Note:

Dental Inventory (Permanent)

State of tooth Key:
P-present; **LPM**-lost post-mortem; **LAM**-lost ante-mortem; **BPM**-broken post-mortem; **NP**- not present; **R**-root only; **U**-unerupted; **E**-erupting; **PE**-partially erupted; **PU**-pulp exposed -jaw not present

	Right									**Left**							
DEH																	
Periapical lesions																	
Periodontal disease																	
Calculus																	
Caries																	
Attrition																	
State of tooth																	
Maxillary	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**



Right **Left**

Mandibular	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
State of tooth																	
Attrition																	
Caries																	
Calculus																	
Periodontal disease																	
Periapical lesions																	
DEH																	

Note:

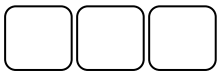
Dental Disease:

Calculus:	A. absent	P. present
Periodontal disease:	A. absent	P. present
Periapical lesions:	A. absent	P. present
DEH:	A. absent	P. present
Caries:	A. absent	P. present
Dental attrition (Smith, 1984):	((grades 1-8) anterior and premolars)	
Note:		

Dental Attrition (Brothwell, 1981):

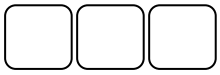
Maxilla

Right



M1 M2 M3

Left



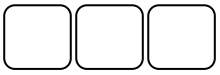
M1 M2 M3

Mandible

Right

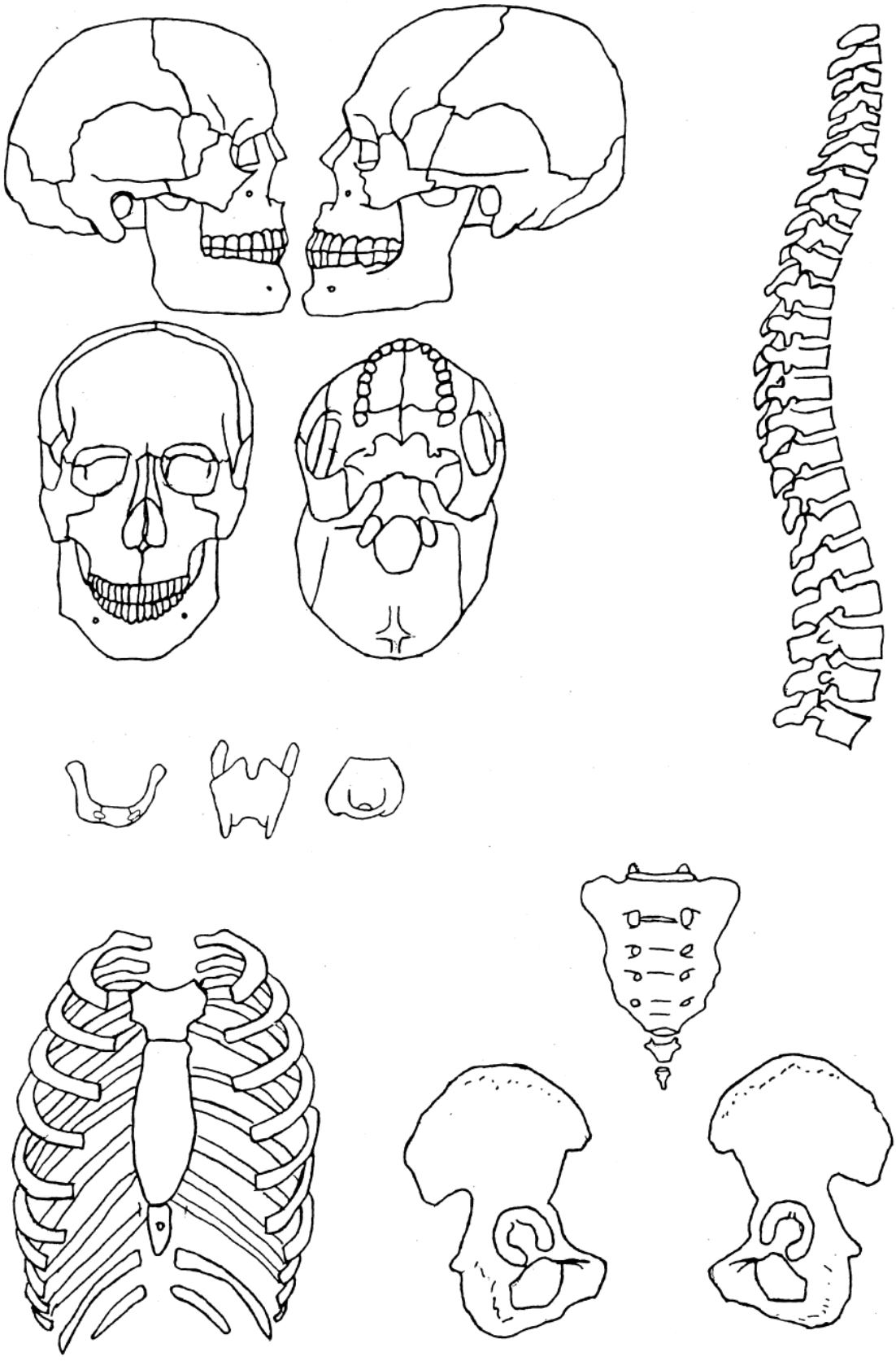
M1 M2 M3

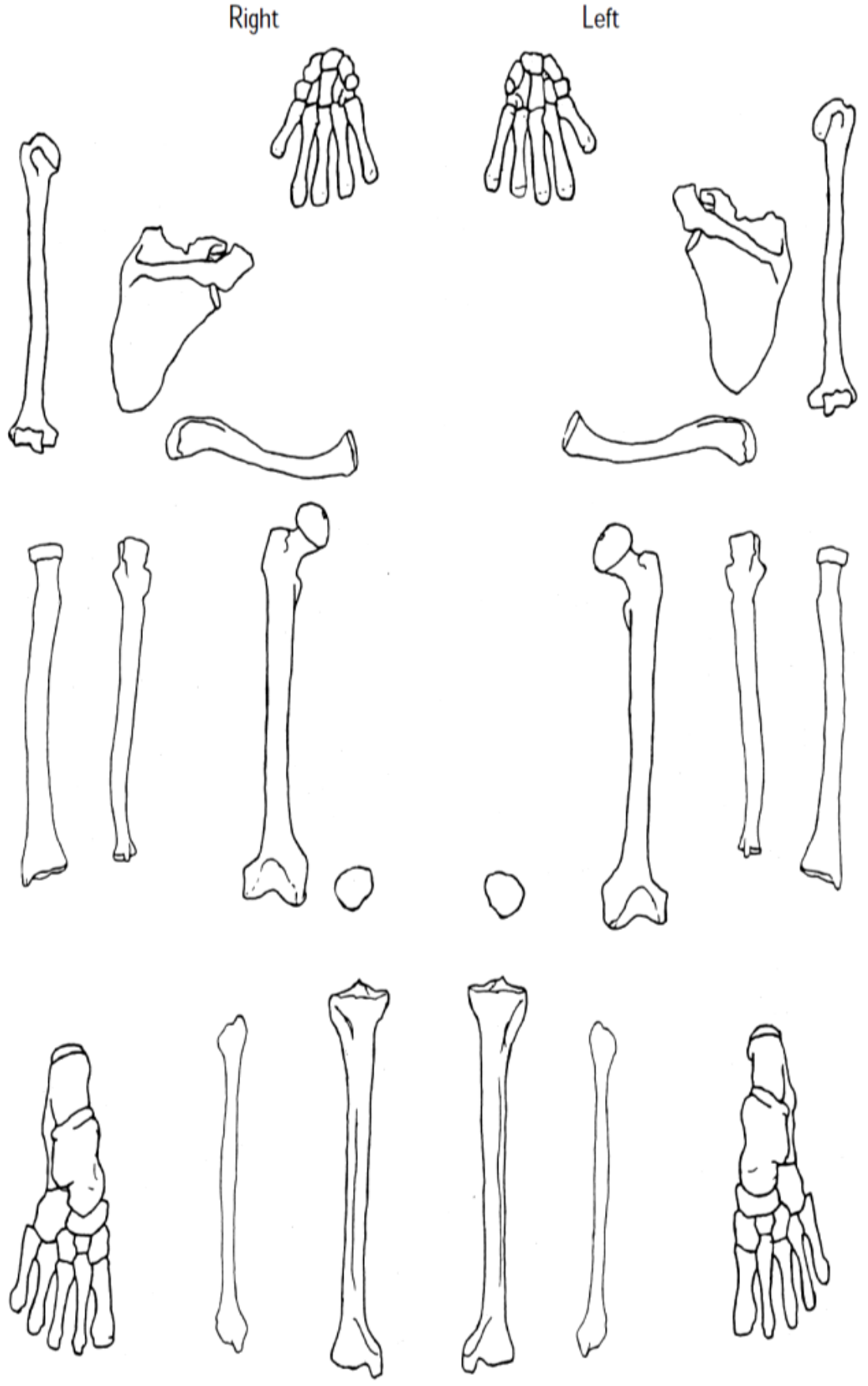
Left



M1 M2 M3

Age Estimated:




Right
Left

Sex-Estimation:

Skull	**M**	**M?**	**I**	**F?**	**F**	**Comment**
Glabella (Ascadi& Nemeskeri, 1970)						
Forehead (Ascadi& Nemeskeri, 1970)						
Orbits (Ascadi& Nemeskeri, 1970)						
Bossing (Ascadi& Nemeskeri, 1970)						
Mastoid processes (Ascadi& Nemeskeri, 1970)						
Post zygomatic arch (Bass, 1995)						
Nuchal crest (Ascadi& Nemeskeri, 1970)						
Mental eminence (Ascadi& Nemeskeri, 1970)						
Supra-orbital margin (Ascadi& Nemeskeri, 1970)						
Shape of chin (Bass, 1995)						
Mandibular ramus flexure (Loth & Henneberg, 1996)						
Flaring of gonial angle (Ascadi& Nemeskeri, 1970)						
Pelvis						
Greater sciatic notch (Ascadi& Nemeskeri, 1970)						
Sub-pubic angle (Bass, 1995)						
Sub-pubic concavity (Phenice, 1969)						
Sub-pubic bone length (Bass, 1995)						
Ischiopubic ramus ridge (Phenice, 1969)						
Ventral arc (Phenice, 1969)						
Obturator foramen/oval= male (Ascadi& Nemeskeri, 1970)						
Pelvic inlet/outlet (Bass, 1995)						
Acetabulum (Bass, 1995)						
Sacrum morphology (Bass, 1995)						
Preauricular-sulcus (Cox, 2000a)						

Metrics (Bass, 1995)	**L**	**R**	**M**	**M?**	**I**	**F?**	**F**
1.Fem. head diam. >48mm=M,<43mm =F							
2.Fem. Bicondylar width >76mm=M,<74mm =F							
3.Humerus head diam. >47mm =M,<43mm=F							
4.Radial head diam. >23mm =M,<21mm =F							
5.Scapula glenoid width >28.6mm =M,<26.1mm =F							
6.Clavicle length >150mm =M,<138mm =F							
Robusticity/ Overall size							

Comment:
Sex:

Age-Estimation (Adult Age):

Skeletal region	**Stage/ unfused/ fused/ line still visible**		**Age**
	L	R	
Dental attrition (Brothwell, 1981)			
Dental attrition (Miles, 1963)			
3rd Molar eruption <25 years (van Beek, 1983)			
Spheno- Occipital fusion (Scheuer & Black, 2000b)			
Medial aspect of clavicle (Black and Scheuer, 1996)			
Sternal end of clavicle fusion (Scheuer & Black, 2000b)			
Sacral fusion (Scheuer & Black, 2000b)			
Iliac crest fusion (Scheuer & Black, 2000b)			
Epiphyseal vertebral rings fusion (Scheuer & Black, 2000b)			
Ischial epiphyseal fusion (Scheuer & Black, 2000b)			
Pubic symphysis degeneration (Brooks and Suchey, 1990)			
Auricular surface morphology (Lovejoy et al., 1985b)			
Sternal ends of ribs (Iscan et al., 1984, 1985)			
Other			

Comments:
Final estimated age:

Dental Measurement:

Maxilla

Tooth	I1		I2		C		PM1		PM2		M1		M2		M3	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Mesiodistal diameter																
Buccolingual diameter																

Mandible

Tooth	I1		I2		C		PM1		PM2		M1		M2		M3	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
Mesiodistal diameter																
Buccolingual diameter																

Dental Non-Metric Traits (Turner et al., 1991)

Mandible

	Right								Left							
	M3	**M2**	**M1**	**P2**	**P1**	**C**	**I2**	**I1**	**I1**	**I2**	**C**	**P1**	**P2**	**M1**	**M2**	**M3**
Shovel																
Congenital absence																
Lingual cusp variation																
Groove pattern																
Cusp number																
Distal trigonid crest																
Protostylid																
Cusp 5																
Cusp 6																
Cusp 7																

New variants/ Extra tooth:

Maxilla

	Right								Left							
	M3	**M2**	**M1**	**P2**	**P1**	**C**	**I2**	**I1**	**I1**	**I2**	**C**	**P1**	**P2**	**M1**	**M2**	**M3**
Winging																
Shovelling																
Labial convexity																
Interruption groove																
Tuberculum dentale																
Mesial ridge																
Distal accessory cusps																
Distosagittal ridge																
Metacone-cusp 3																
Hypocone-cusp 4																
Metaconule-cusp5																
Carabelie's Trait																
Parastyle																
Enamel extensions																
Congenital absence																

New variants/ Extra tooth:

Cranial and Post-Cranial Non-Metric Traits:

	Cranial Traits (Berry & Berry, 1967)	L	R	Unobservable - description	Post-cranial Traits (Finnegan, 1978)	L	R	Unobservable-description
1	Highest nuchal-line present				Allen's Fossa			
2	Ossicle at lambda				Poirier's facet			
3	Lambdoid ossicle present				Plaque			
4	Parietal foramen present				Hypotrochanteric fossa			
5	Bregmatic bone present				Exostosis in trochanteric fossa			
6	Metopism				Third trochanter			
7	Coronal ossicle present				Medial tibial squatting-facet			
8	Epipteric bone present				Lateral tibial squatting-facet			
9	Frontotemporal articulation				Supralcondyloid process			
10	Parietal notch bone present				Septal-aperture			
11	Ossicle at asterion				Acetabular crease			
12	Auditory torus present				Preauricular-sulcus			
13	Foramen of Huschke				Accessory sacral facets			
14	Mastoid foramen exsutural				Acromial articular facets			
15	Mastoid foramen absent				Suprascapular foramen			
16	Posterior condylar canal				Circumflex sulcus			
17	Condylar facet double				Vastus notch			
18	Precondylar tubercle				Vastus fossa			
19	Anterior condylar canal double				Emarginate patella			
20	Foramen oval incomplete				Os trigonum			
21	Foramen spinosum open				Medial talar facet			
22	Accessory lesser palatine foramen				Lateral talar extension			
23	Palatine torus/location/ size				Inferior talar articular surface			
24	Maxillary torus/location/ size				Anterior calcaneal facet double			
25	Zygomatico-facial foramen absent				Anterior calcaneal facet absent			
26	Supra-orbital foramen complete				Peroneal tubercle present			
27	Frontal notch or foramenn present				Atlas facet form double			
28	Anterior ethmoid foramen exsutural				Posterior bridge present			
29	Posterior ethmoid foramen				Lateral bridge present			
30	Accessory infraorbital foramen				Transverse foramen bipartite			

New Traits:

Cranial Measurements:

Biometric code		Description	L	R	Fragmented /not present
Brothwell (1981)	Buikstra & Ubelaker (1994)				
L	1	Maximum cranial length			
B	2	Maximum cranial breadth			
J	3	Bizygomatic diameter			
H'	4	Basion-bregma height			
LB	5	Cranial base length			
-	9	Biauricular breadth			
G'H	10	Upper facial height			
B'	11	Minimum frontal breadth			
-	12	Upper facial breadth			
NH'	13	Nasal height			
NB	14	Nasal breadth			
O'1	15	Orbital breadth			
O2	16	Orbital height			
-	17	Biorbital breadth			
-	18	Interorbital breadth			
S'1	19	Frontal chord			
S'2	20	Parietal chord			
S'3	21	Occipital chord			
FL	22	Foramen magnum length			
FB	23	Foramen magnum breadth			
	24	Mastoid length			
S1	-	Frontal arc			
S2	-	Parietal arc			
S3	-	Occipital arc			

Post-Cranial Measurements:

Brothwell (1981)	Buikstra & Ubelaker (1994)	Description	L	R
Code				
HuL1	40	Maximum humeral length		
RaL1	45	Maximum radius length		
UlL1	48	Maximum ulna length		
FeL1	60	Maximum femural length		
TiL1	69	Maximum tibial length		
FiL1	75	Maximum fibula length		

Note:

Stature (Trotter, 1970):

Cranial Trauma:

Bone	Side	Type of fracture	Fracture position	Size	Healing

Note:

Metabolic Disease:

Porotic Hyperostosis (Stuart-Macadam, 1991)

Cribra orbitalia		**Vault lesions**		
L/orbit	R/orbit	Frontal	Parietal	Occipital
Present/Absent	Present/Absent	P/A	P/A	P/A

Note:

Signs of Scurvy:

Note:

Signs of Residual Rickets/ Osteomalacia:

Note:

Signs of Osteopenia/ Osteoporosis:

Note:

Comments:

APPENDIX 2

Project Database

This database is available via the CD attached to the printed thesis. Please contact the author for additional copies.

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